Neutrino Mass, Inflation, and Dark Energy with the CMB

Prof. Neelima Sehgal
Stony Brook University

DOE Cosmic Visions Dark Energy
Oct. 1st, 2015

Outline

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- Intro to ACTPol, AdvACT, CMB-S4

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- Neutrino Mass from CMB Lensing

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ACTPol / AdvACT

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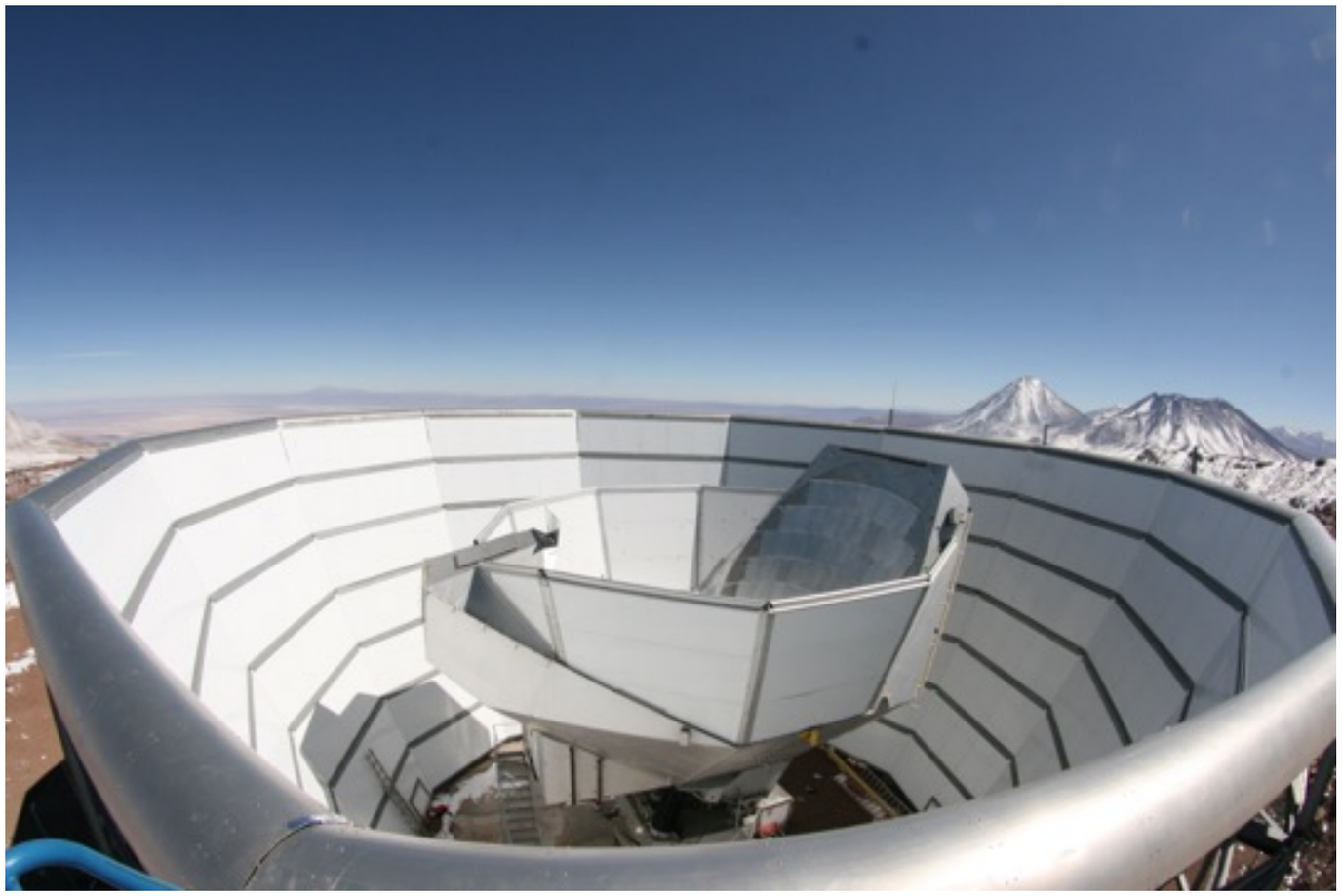

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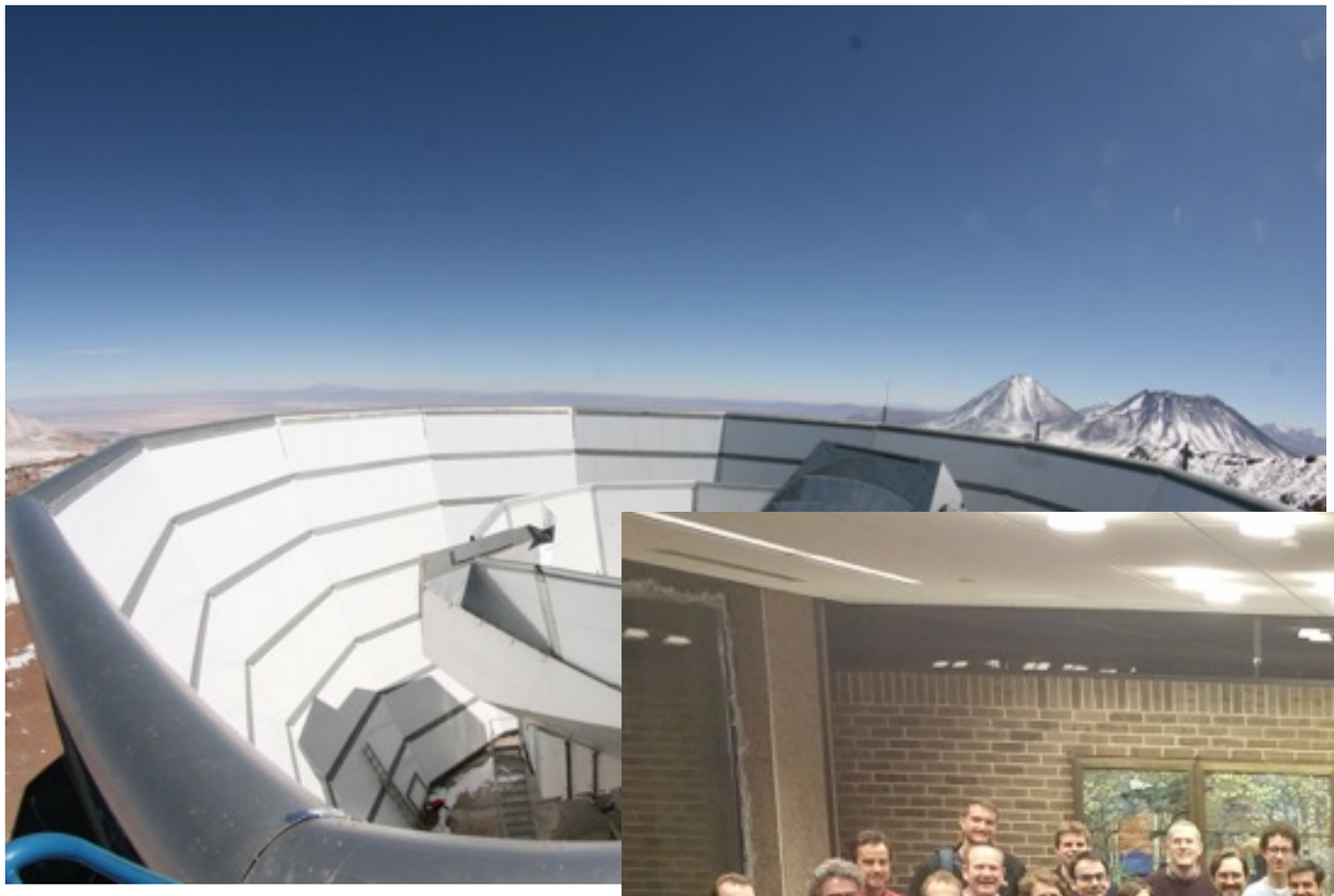

ACTpol / AdvACTpol

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ACTpol / AdvACTpol

ACTpol - Observes from 2013 - 2015

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ACTpol / AdvACTpol

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4000 sq deg (10% of sky)

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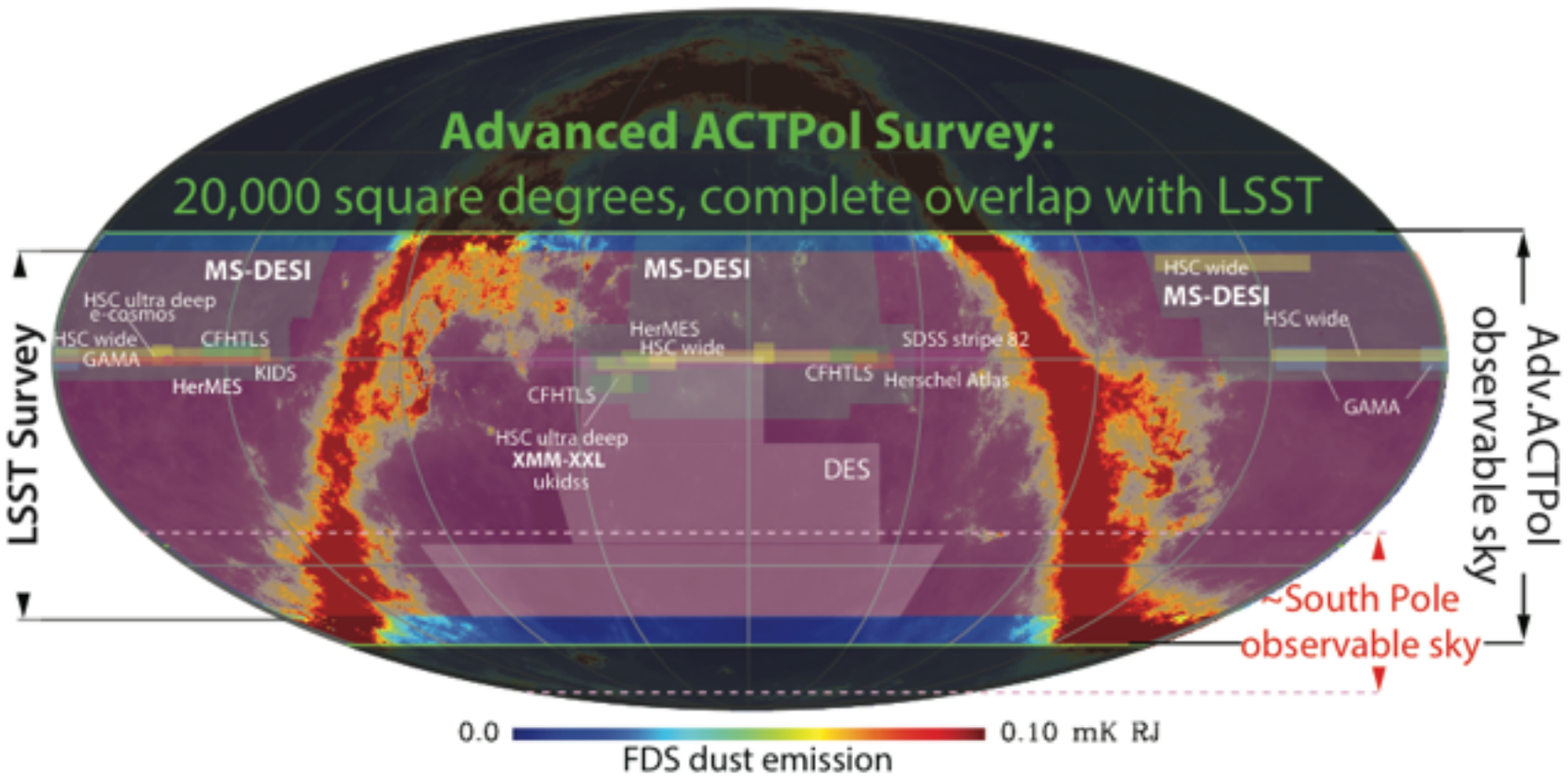

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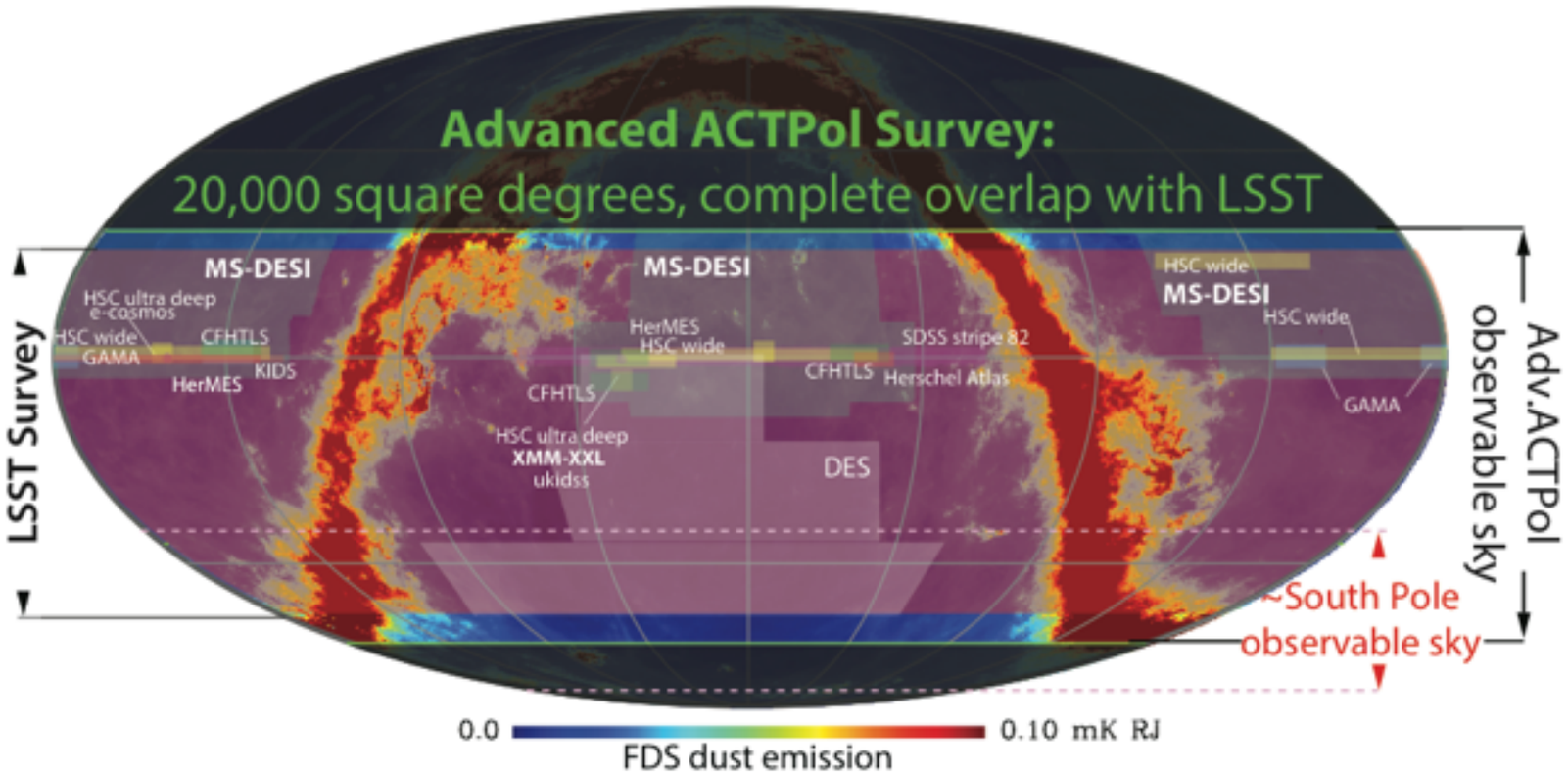

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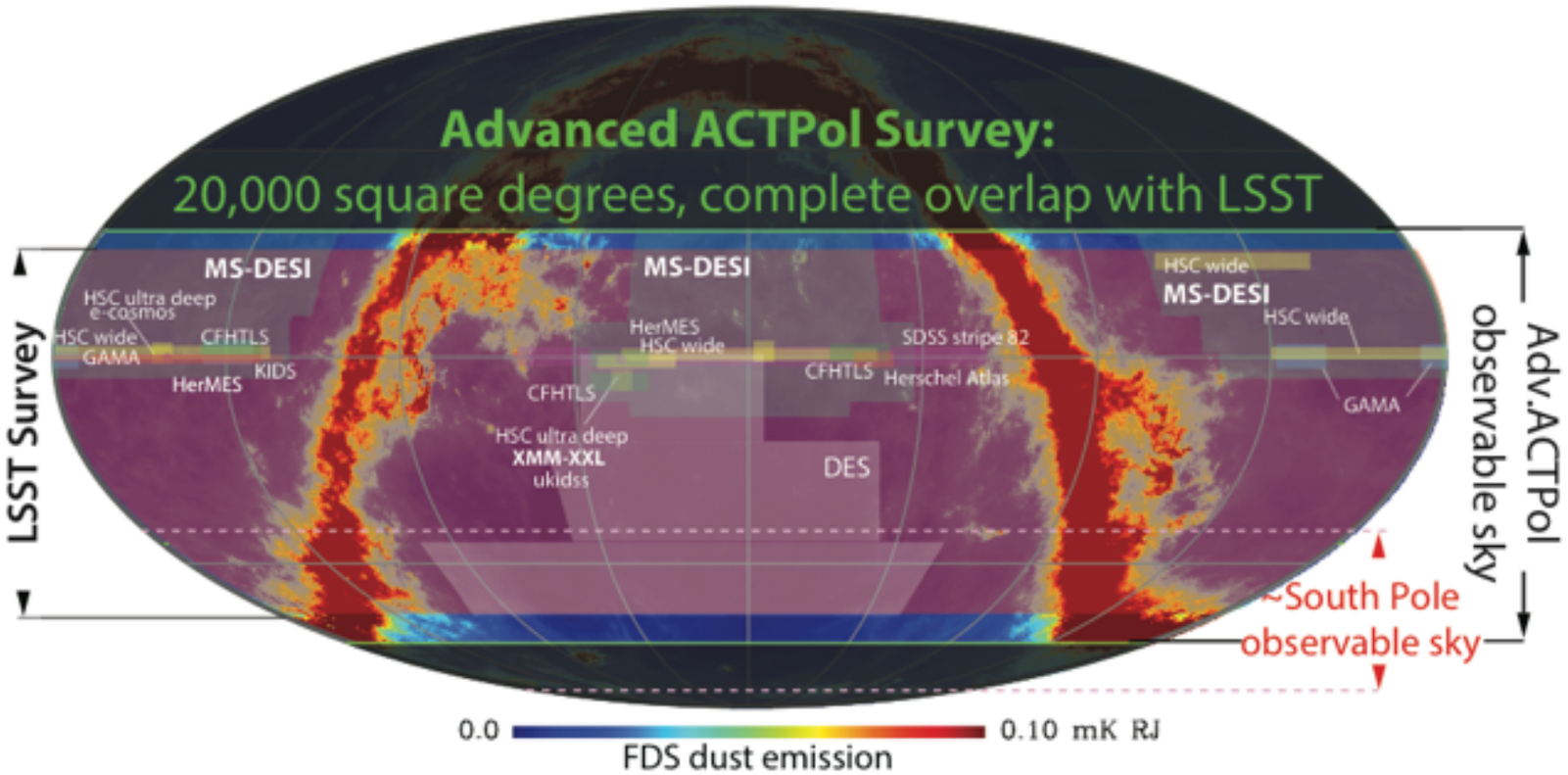

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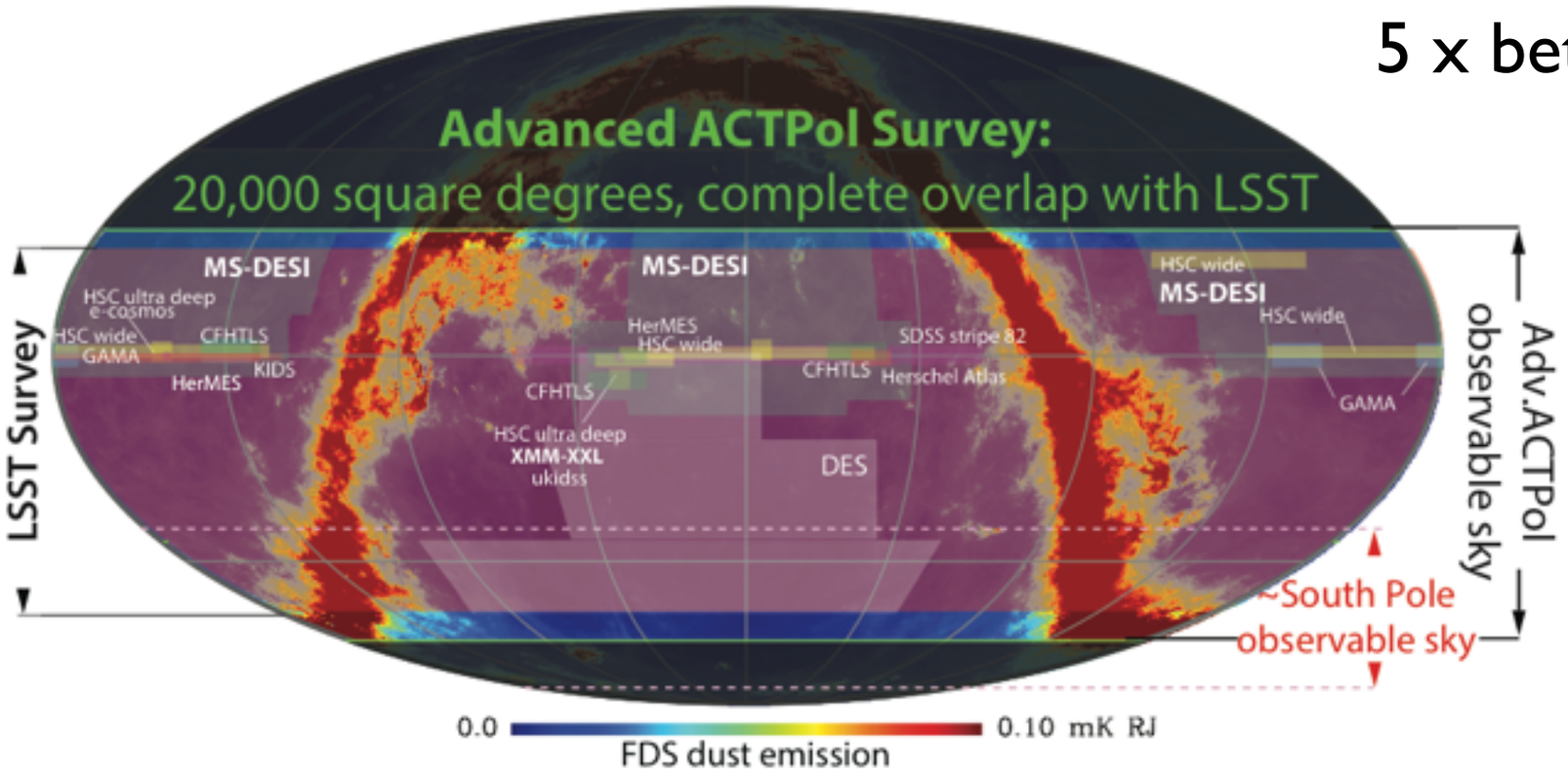

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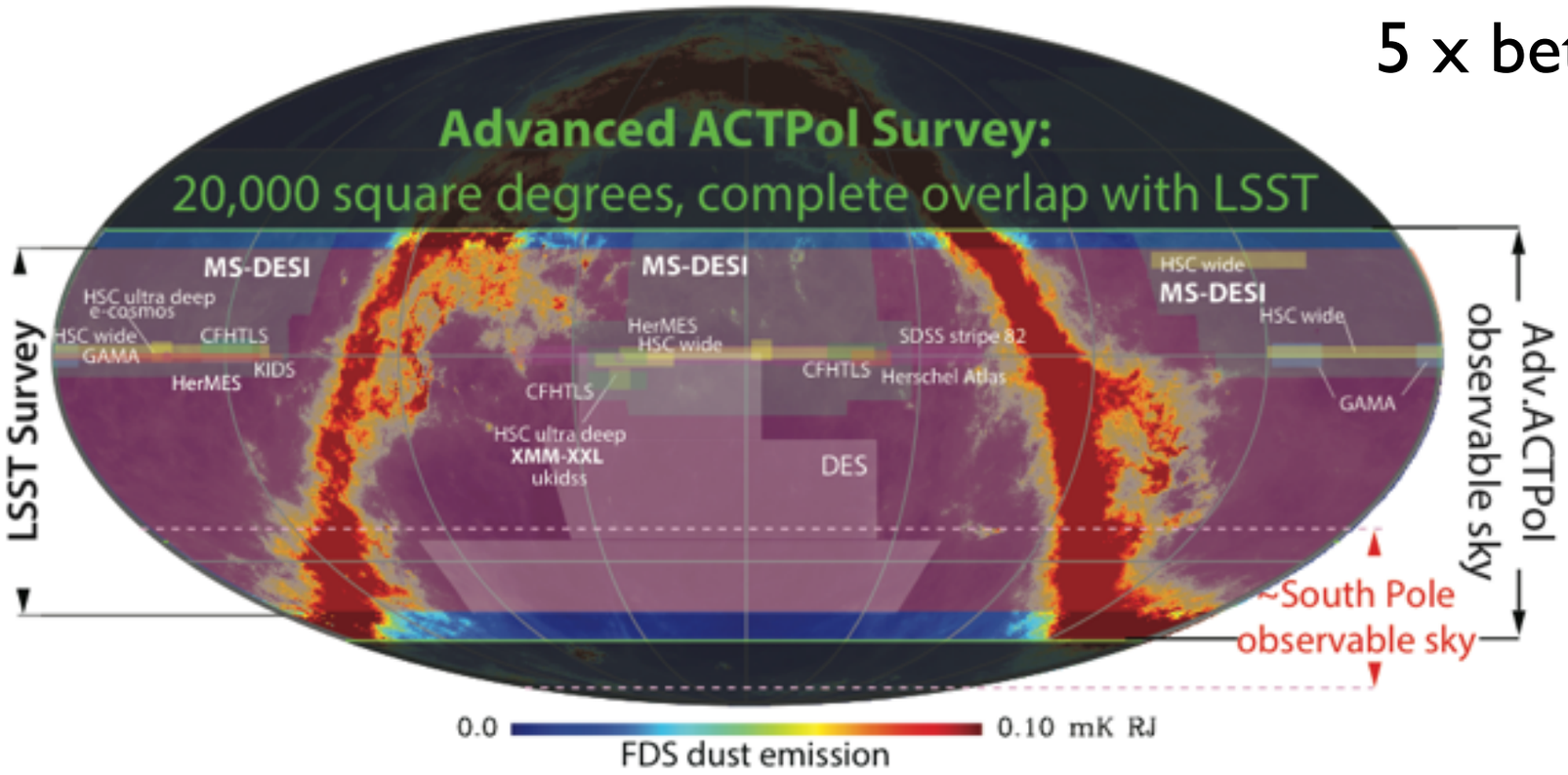

AdvACT funded by NSF MSIP in June 2015

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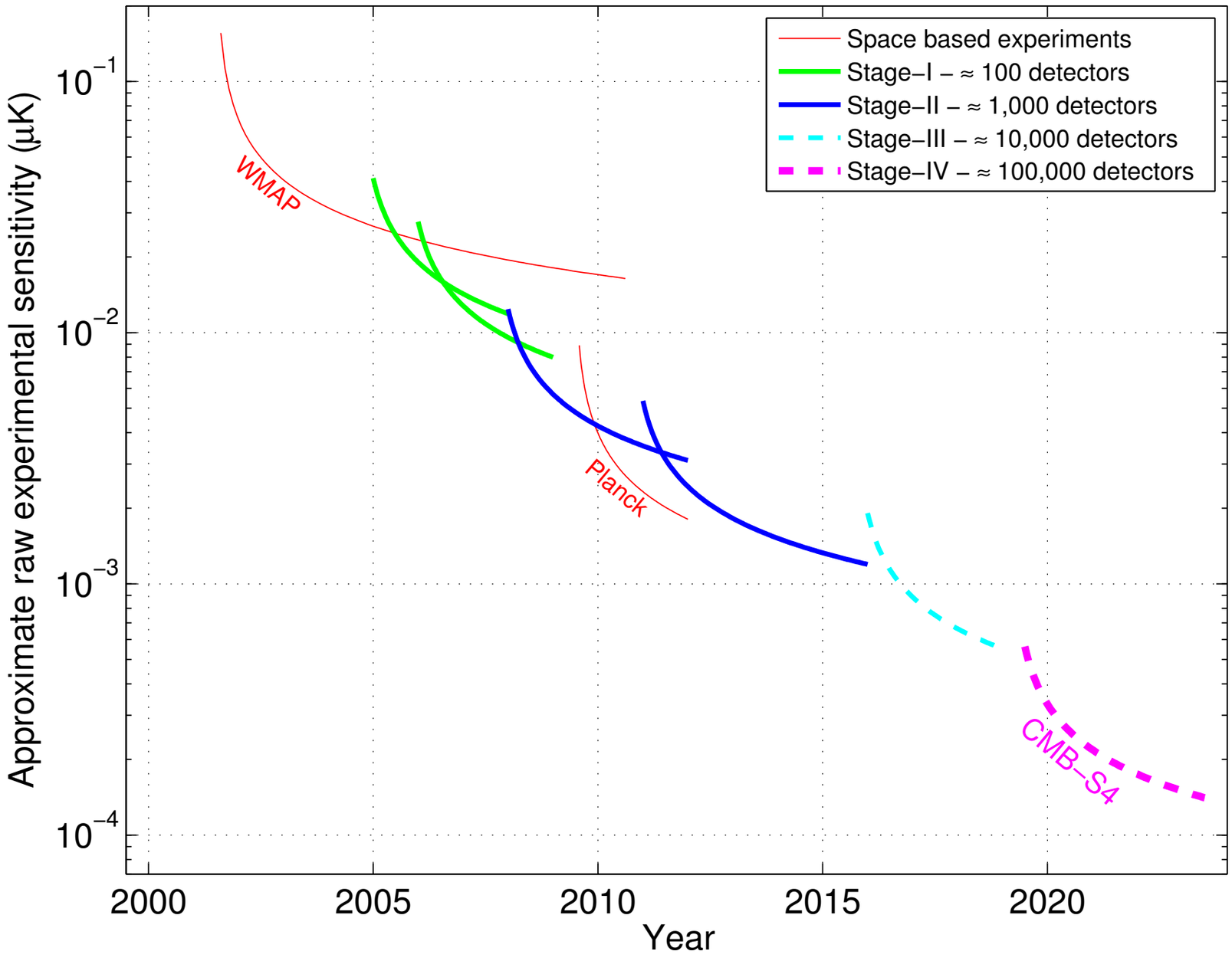
CMB-S4



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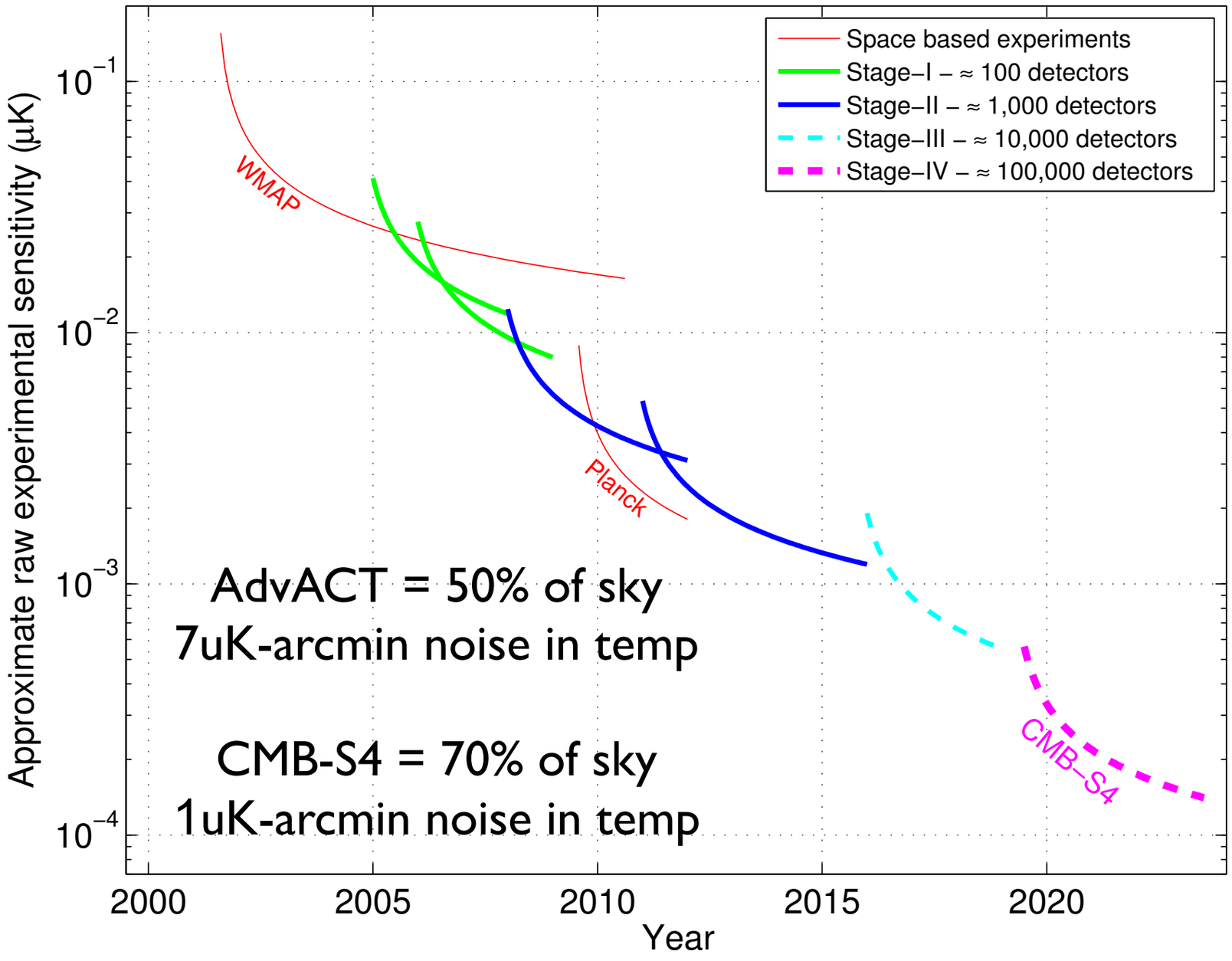

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CMB-S4

Building for Discovery

Strategic Plan for U.S. Particle Physics in the Global Context

Report of the Particle Physics Project Prioritization Panel (P5)

	Scenarios			Science Drivers					
Project/Activity	**Scenario A**	**Scenario B**	**Scenario C**	**Higgs**	**Neutrinos**	**Dark Matter**	**Cosm. Accel.**	**The Unknown**	**Technique (Frontier)**
Large Projects									
Muon program: Mu2e, Muon g-2	Y, Mu2e small reprofile needed	Y	Y					✓	I
HL-LHC	Y	Y	Y	✓		✓		✓	E
LBNF + PIP-II	Y, LBNF components delayed relative to Scenario B.	Y	Y, enhanced		✓			✓	I,C
ILC	R&D only	R&D, possibly small hardware contributions. See text.	Y	✓		✓		✓	E
NuSTORM	N	N	N		✓				I
RADAR	N	N	N		✓				I
Medium Projects									
LSST	Y	Y	Y		✓		✓		C
DM G2	Y	Y	Y			✓			C
Small Projects Portfolio	Y	Y	Y		✓	✓	✓	✓	All
Accelerator R&D and Test Facilities	Y, reduced	Y, some reductions with redirection to PIP-II development	Y, enhanced	✓	✓	✓		✓	E,I
CMB-S4	Y	Y	Y		✓		✓		C

CMB-S4

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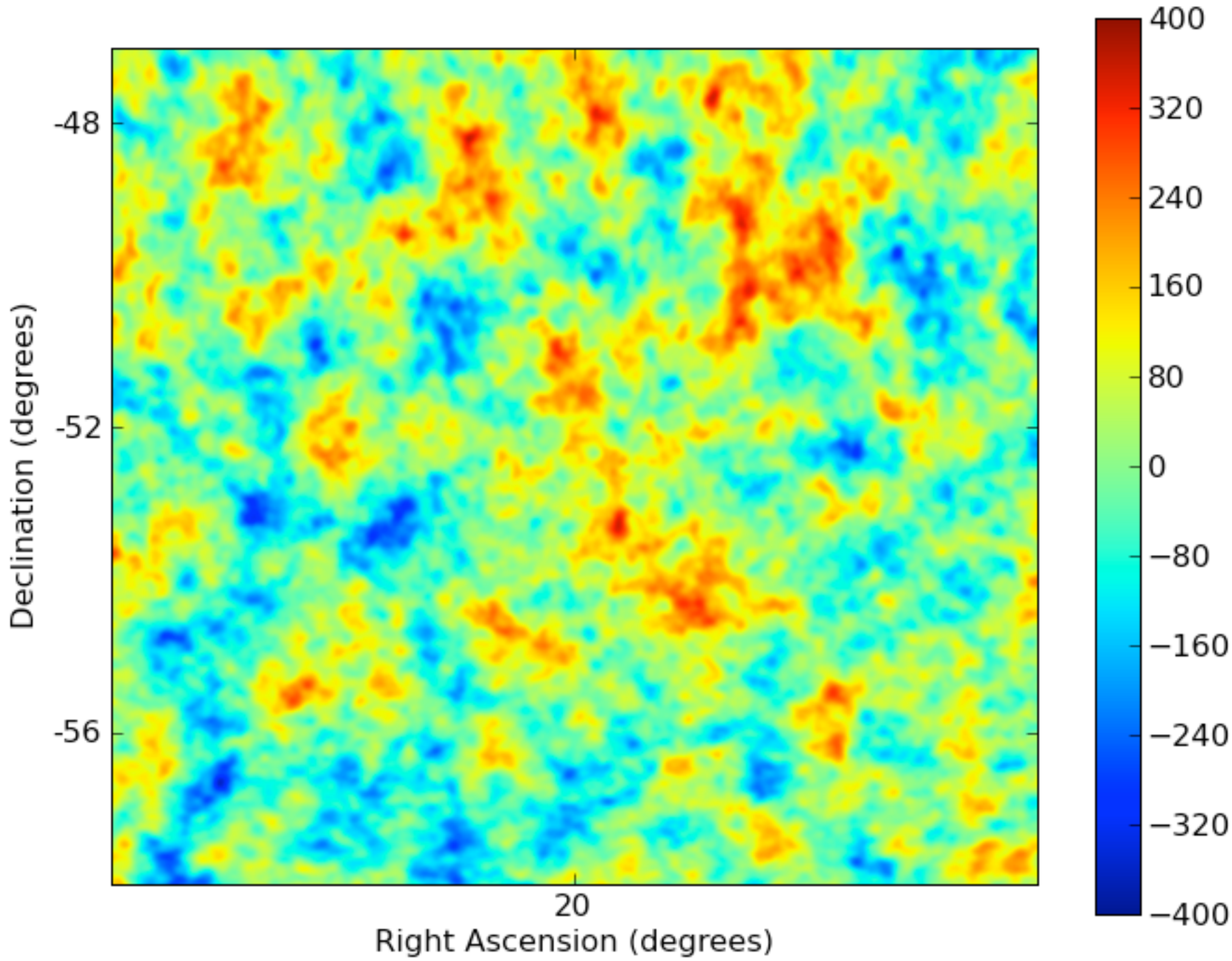
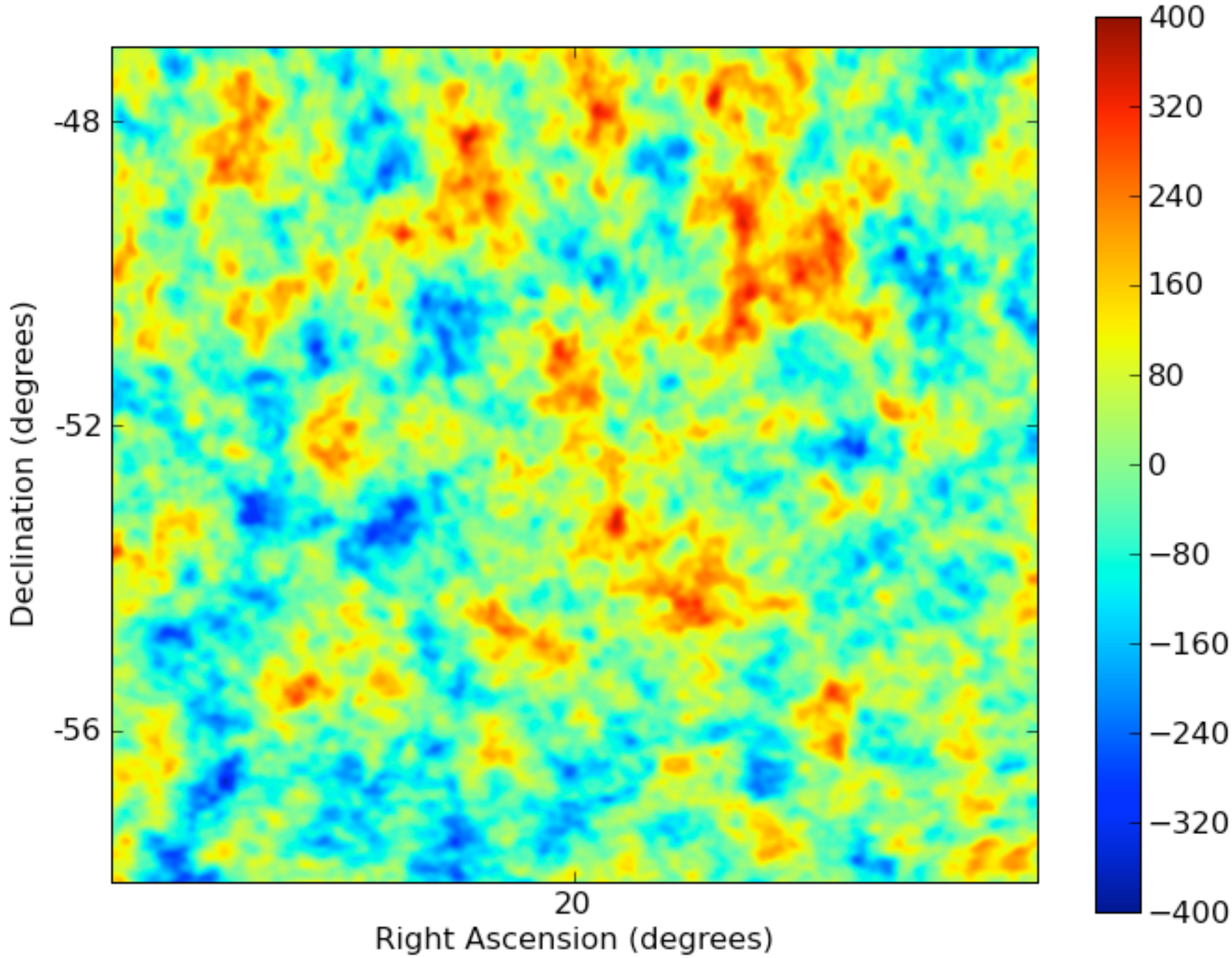
Unlensed CMB



Lensed CMB



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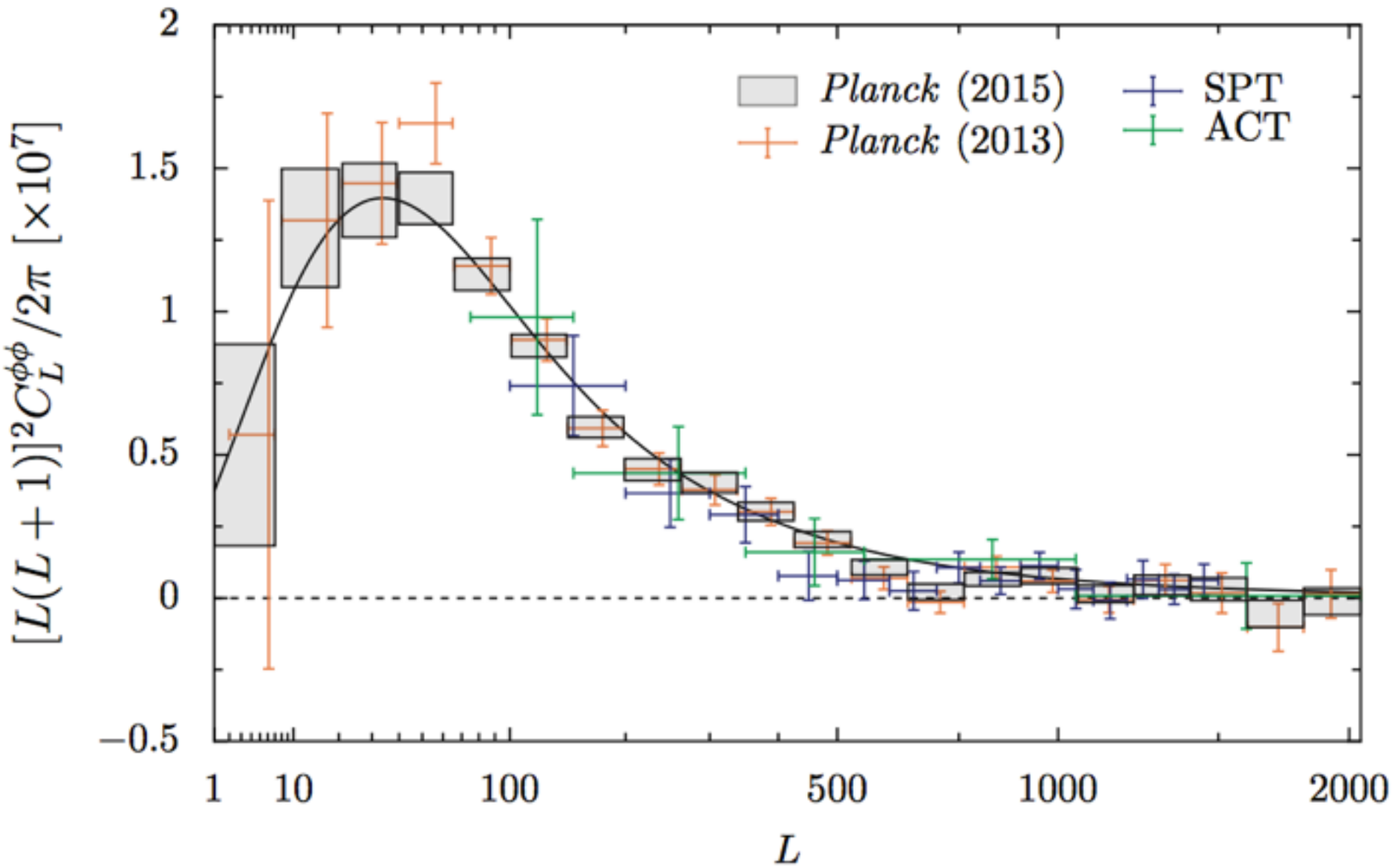
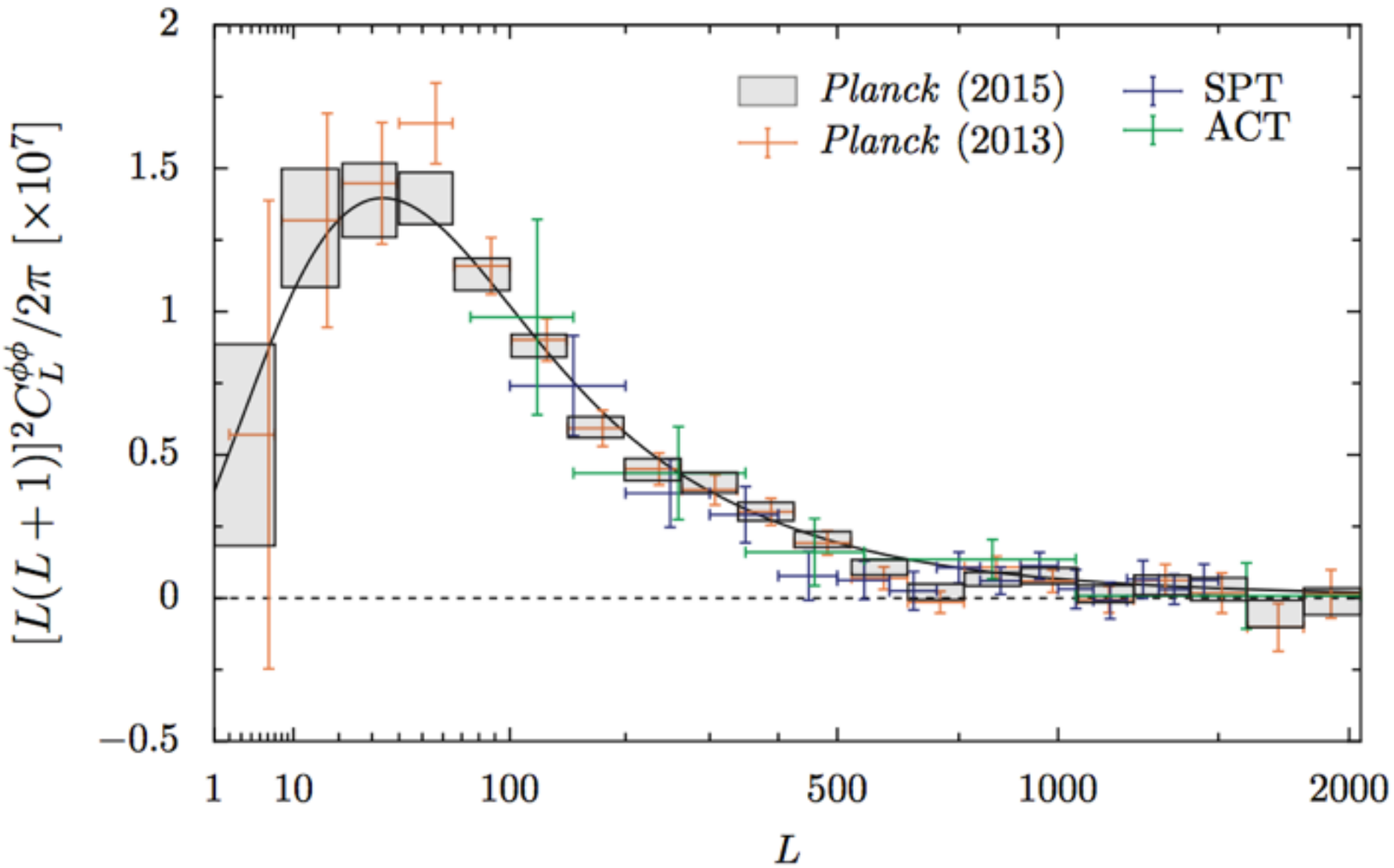
Measurements of CMB Lensing on Large Scales



Planck Paper 15, 2015 (1502.01591)

Measurements of CMB Lensing on Large Scales



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Blanchard & Schneider 1987
(first idea of detectability)

Zaldarriaga & Seljak 1997
(first lensing estimators)

Hu 2001
Hu & Okamoto 2002
(optimal lensing estimators)

Smith, Zahn, Dore 2007
(first indirect detection)

Das et al. 2011 - ACT
(first direct detection)

van Engelen et al. 2012 - SPT
(second direct detection)

Planck Collaboration 2013
(detection with S/N = 25)

Planck Collaboration 2015
(detection with S/N = 40)

CMB Lensing Power Spectrum Sensitive to Neutrino Mass

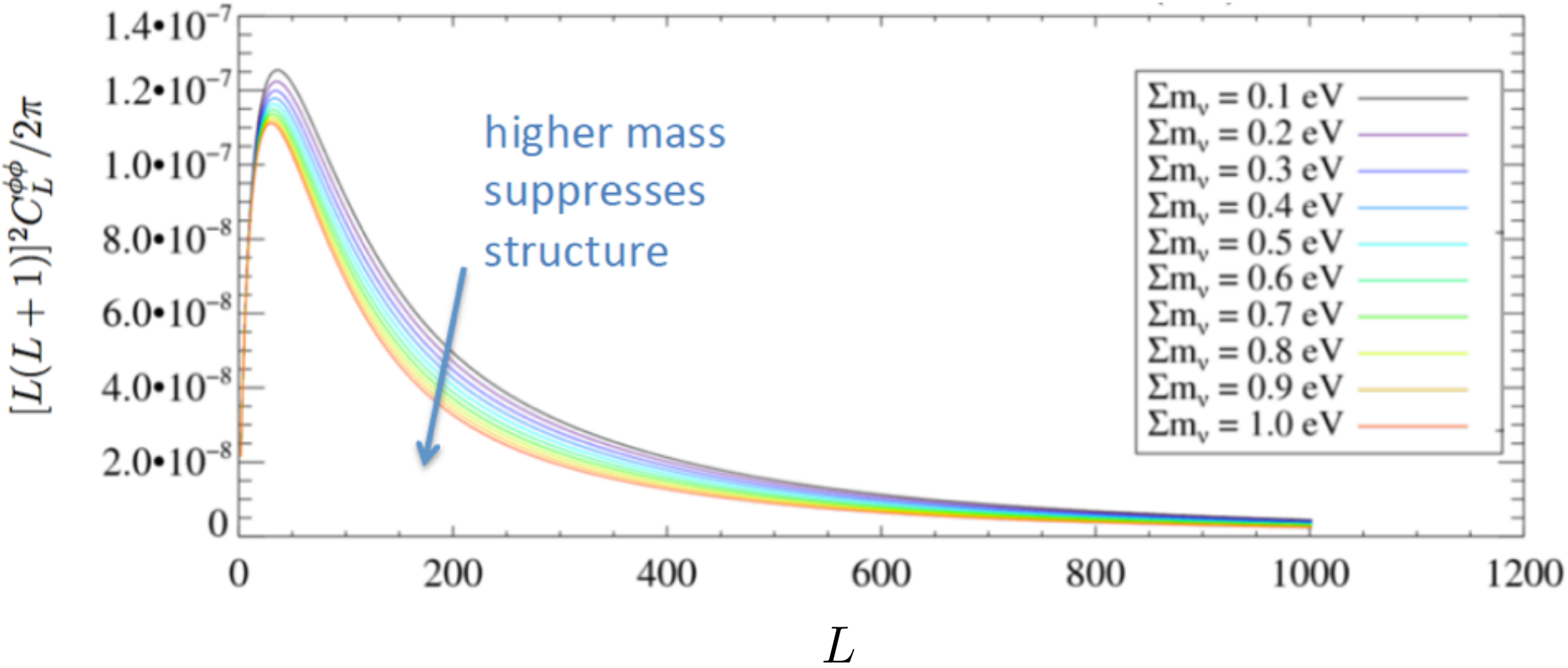

Figure credit: A. van Engelen

ACTPol and AdvACT Forecasts

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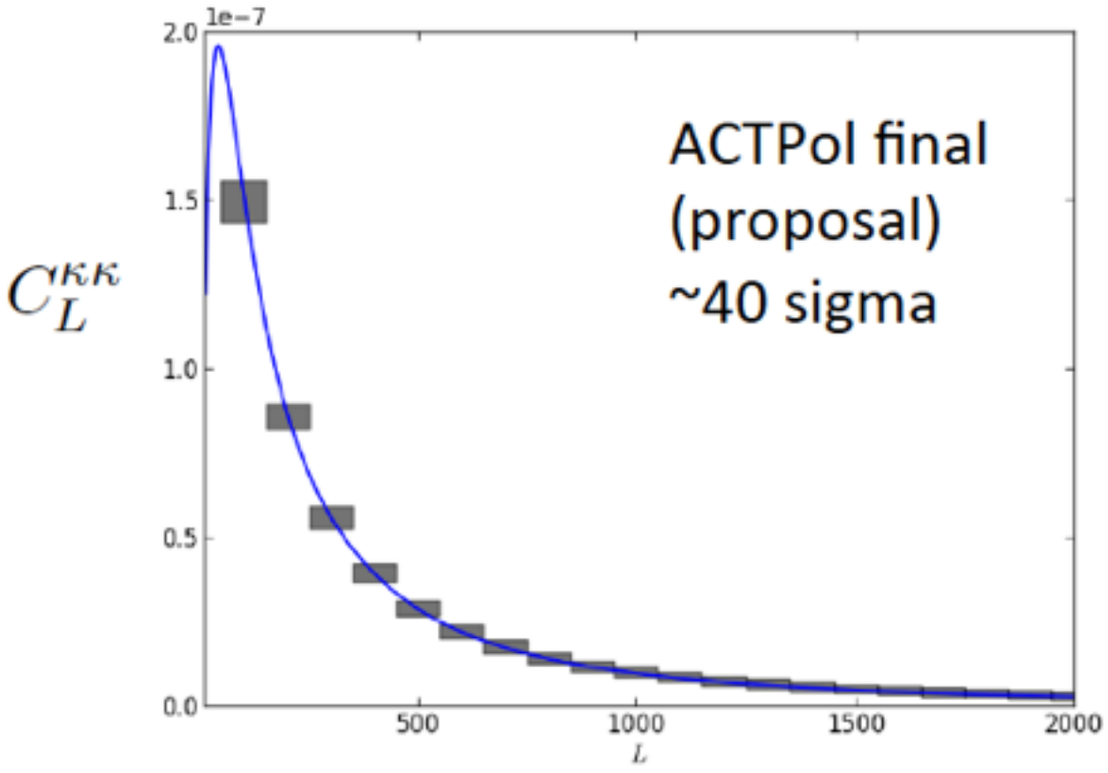

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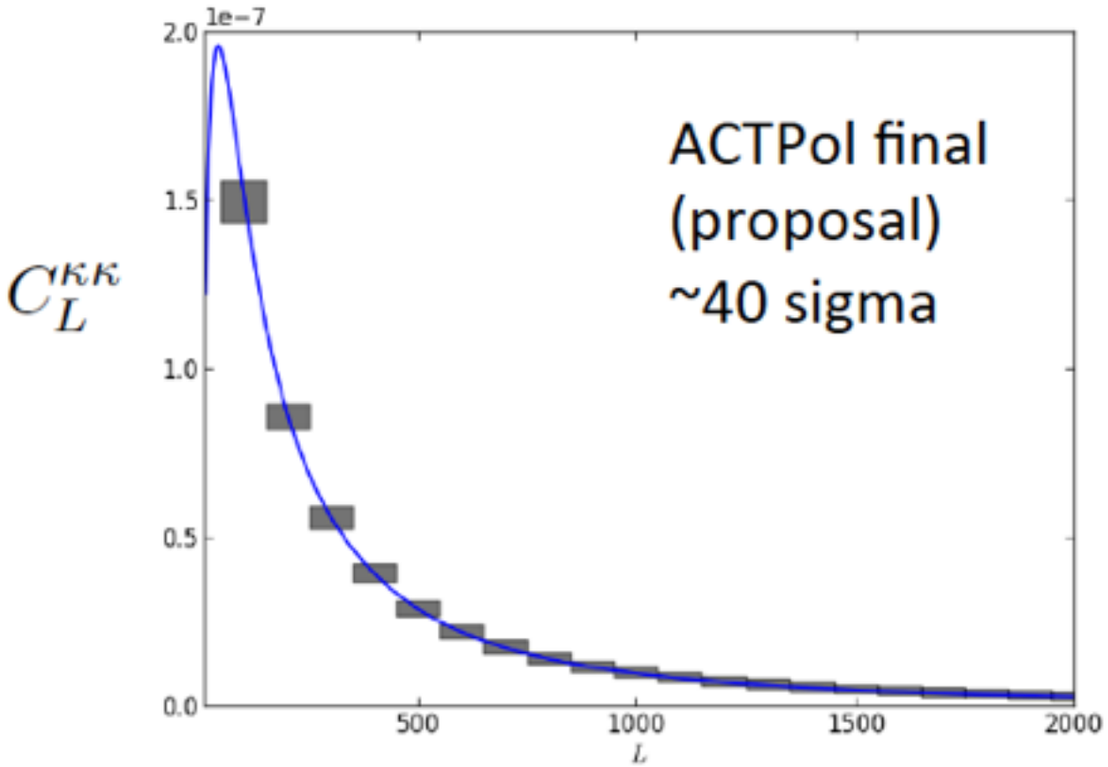

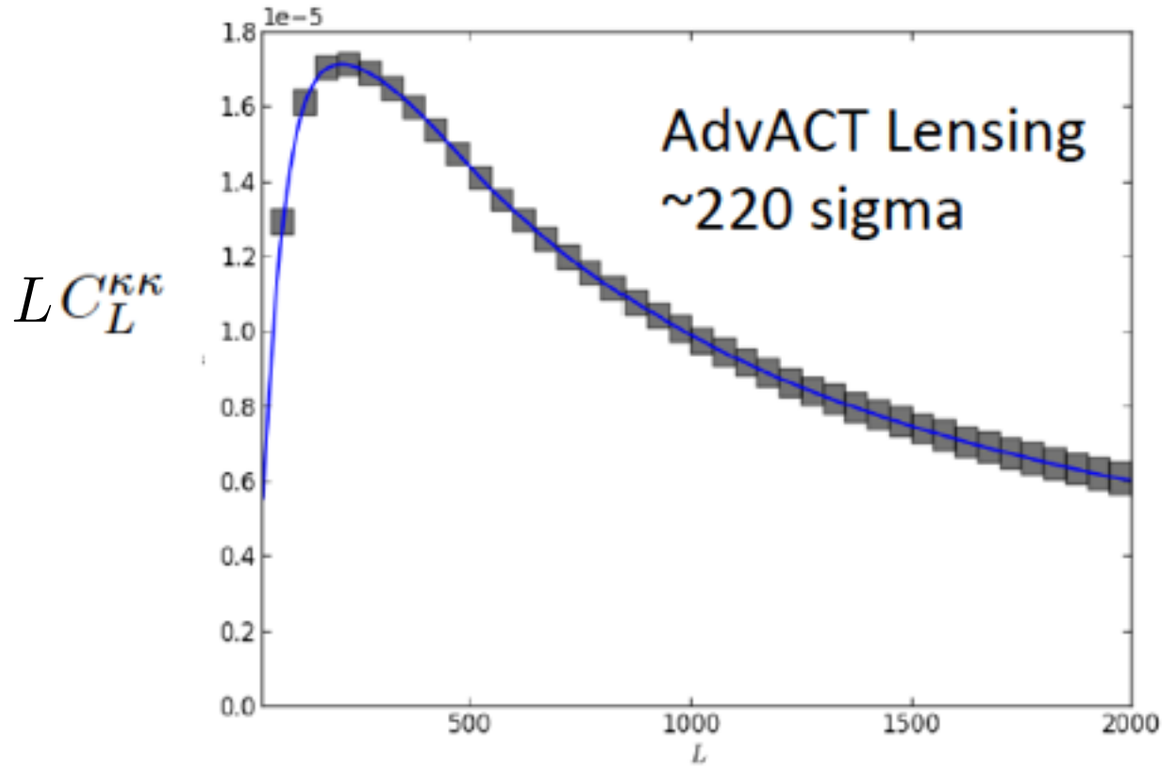

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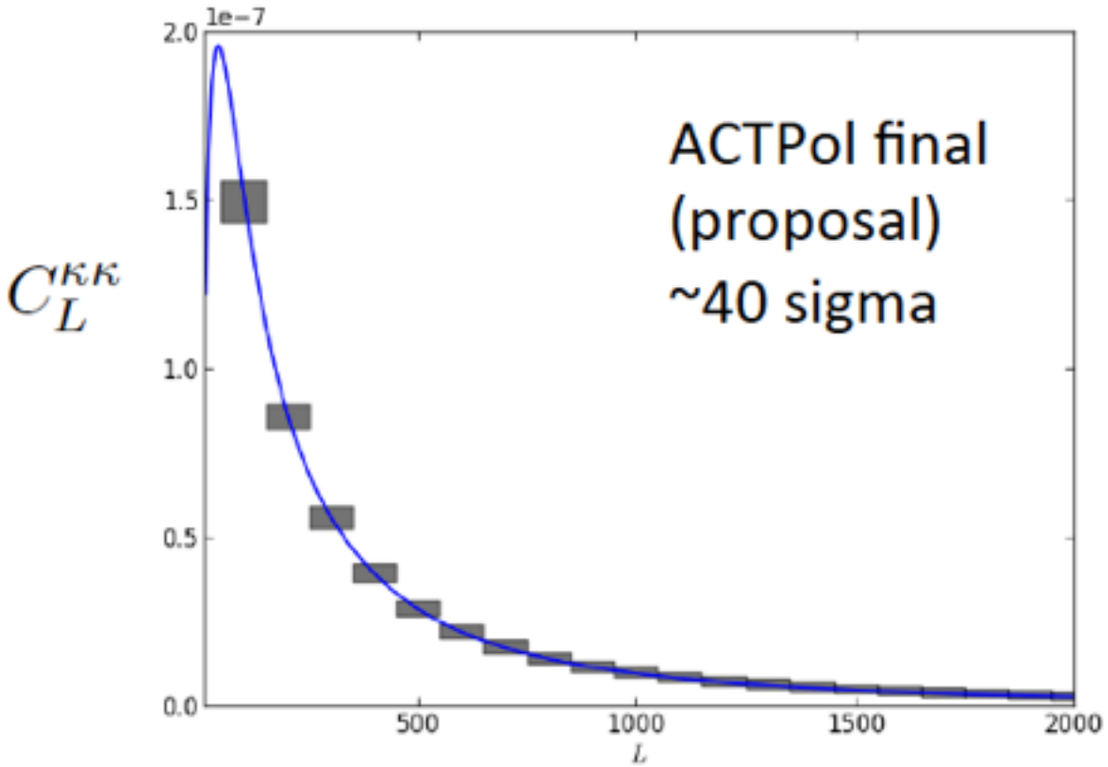
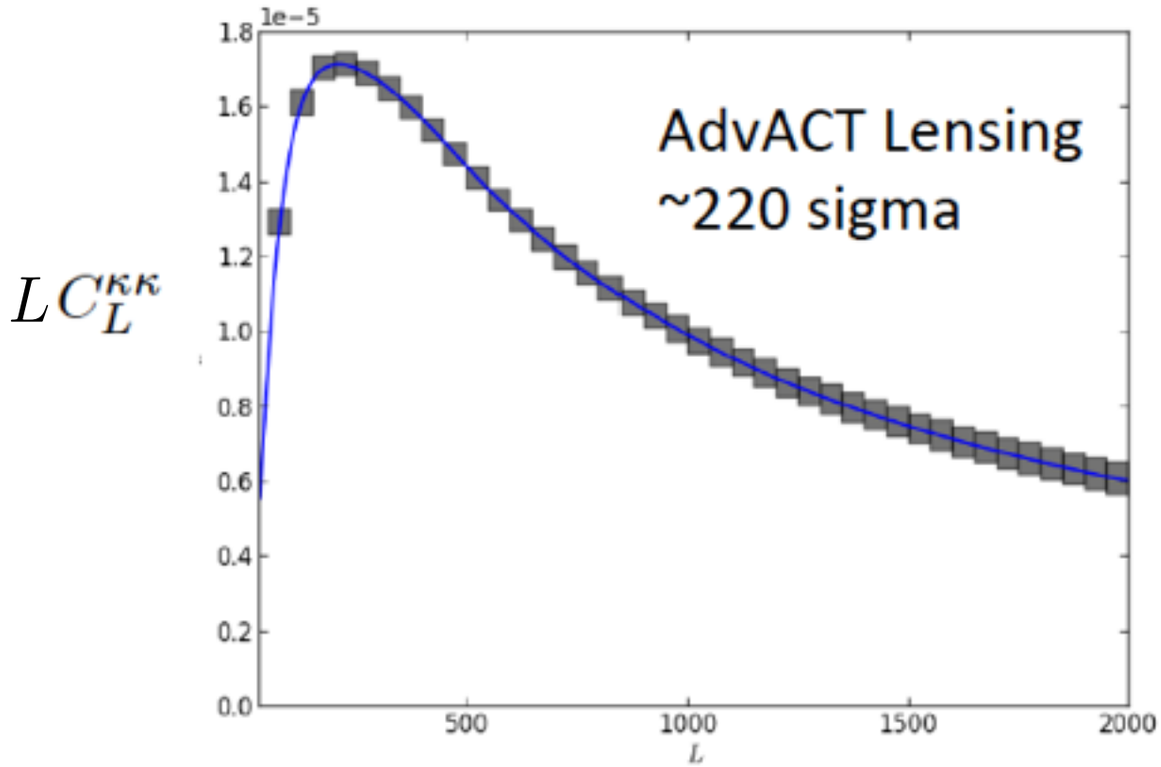
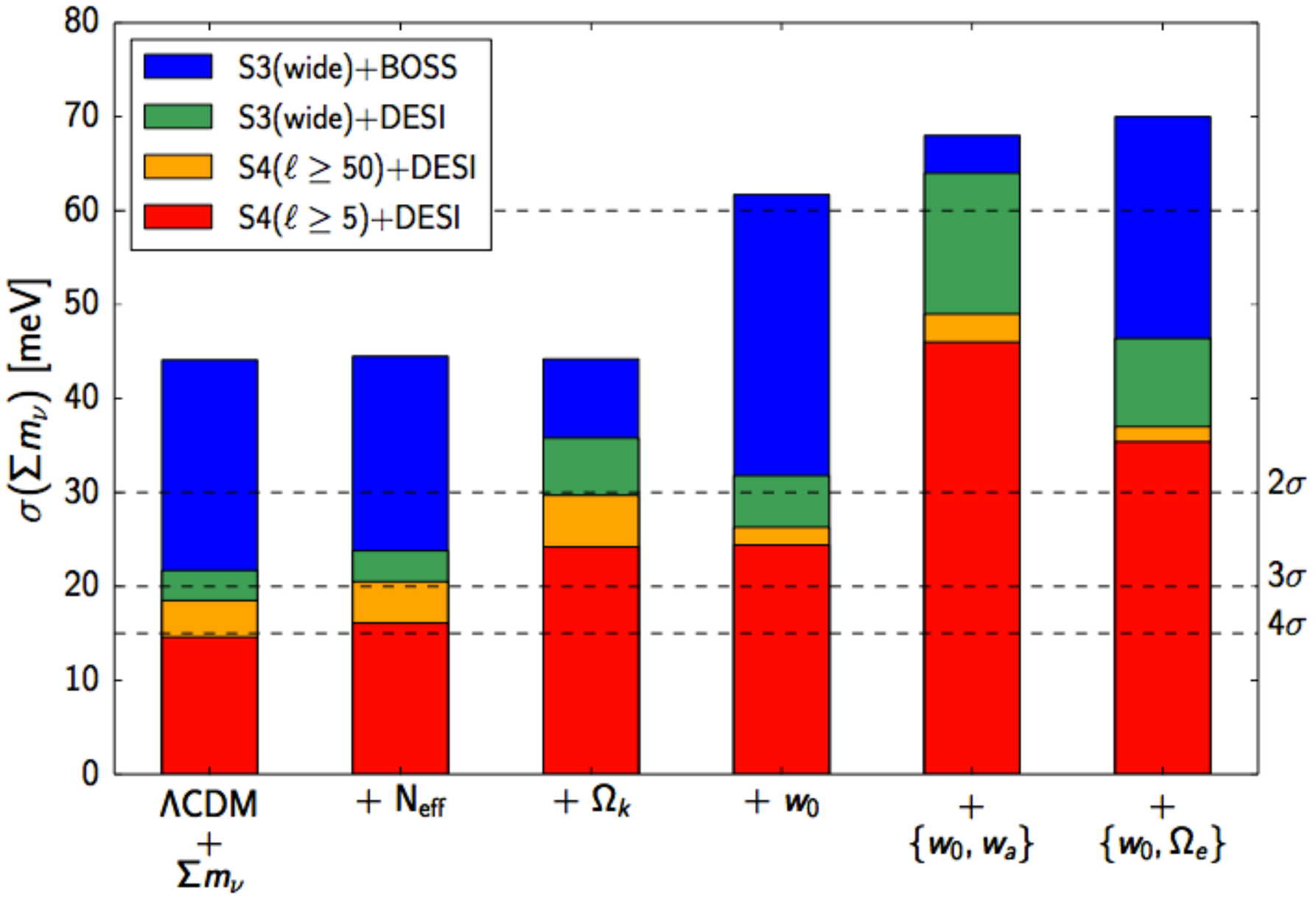




Data Set	f_{sky}	Map noise (μK-arcmin) at 150 GHz	$\sigma(\sum m_\nu)$ (eV) CMB alone	$\sigma(\sum m_\nu)$ (eV) with BAO
Planck	0.8	43	0.20	0.12
ACTPol	0.1	20	0.09	0.06
AdvACT	0.5	7	0.06	0.04

CMB-S4 Forecasts



Allison et al., 1509.07471, 2015

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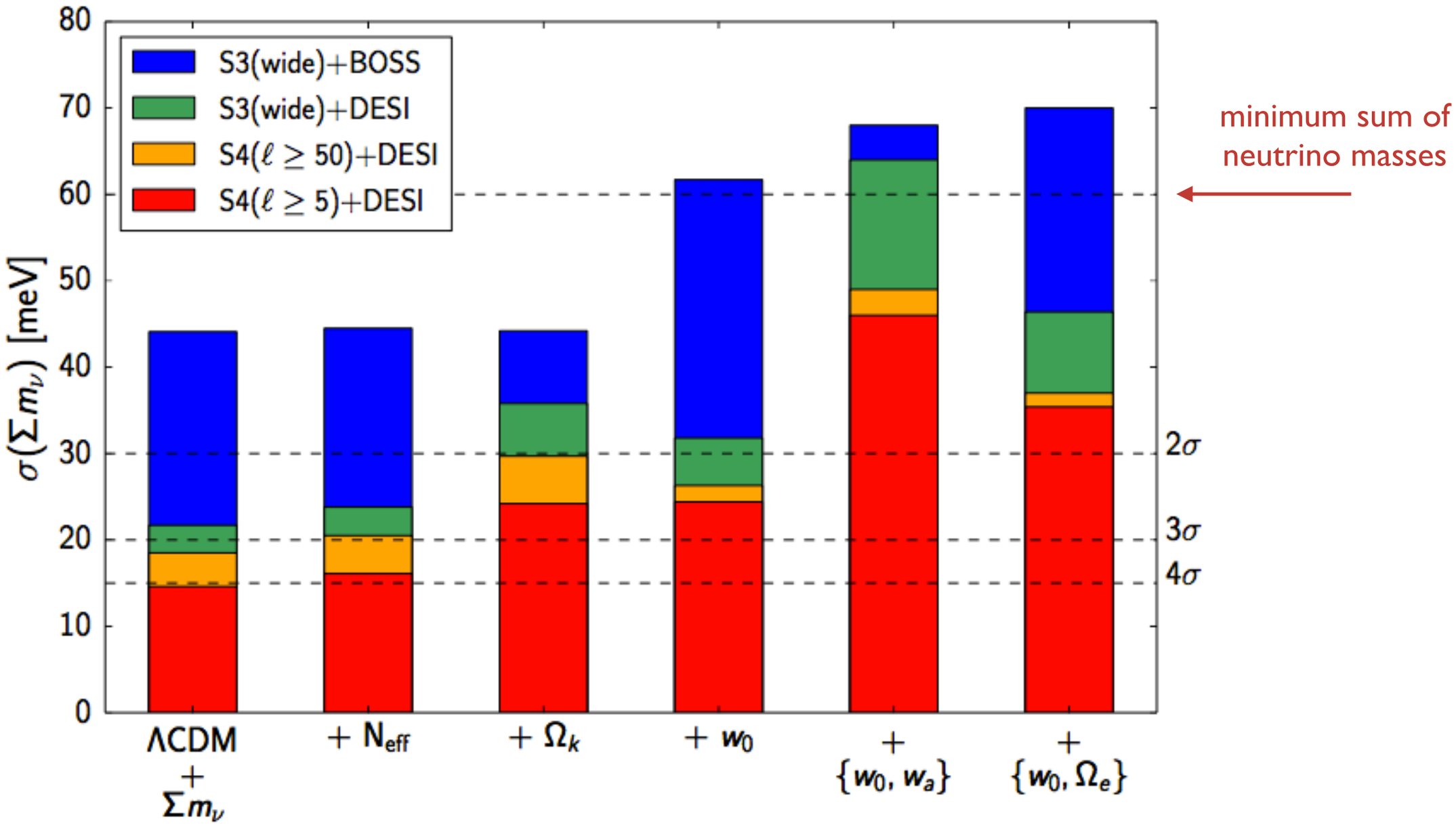

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Delensing Motivation

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Deflection angle

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Projected lensing potential

Deflection angle

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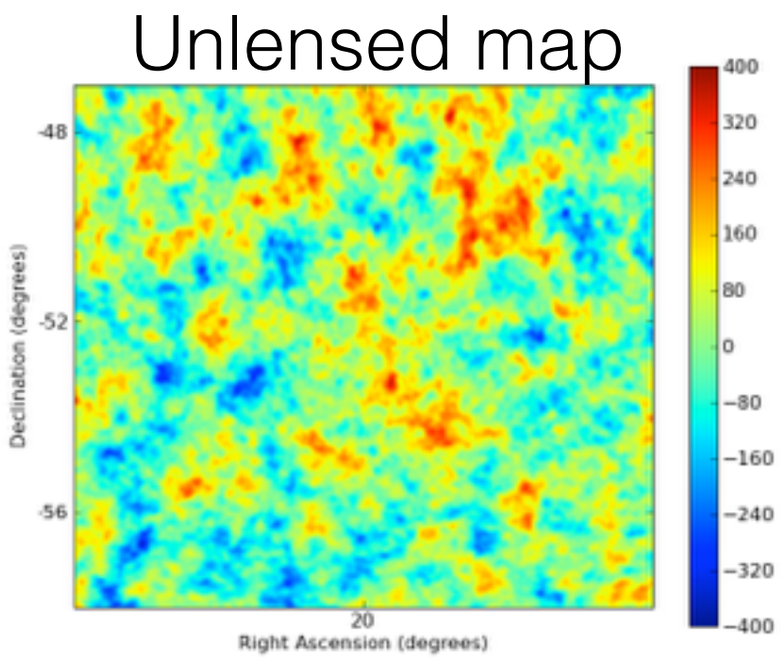

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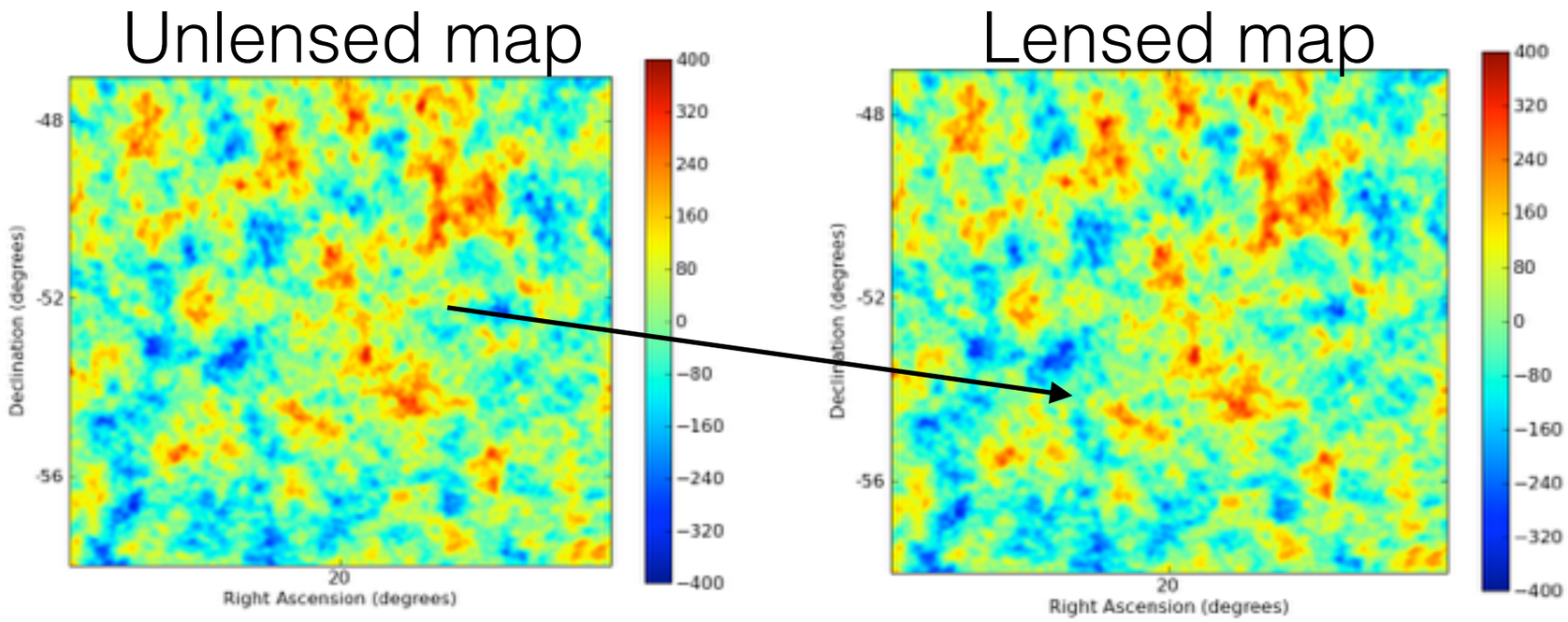

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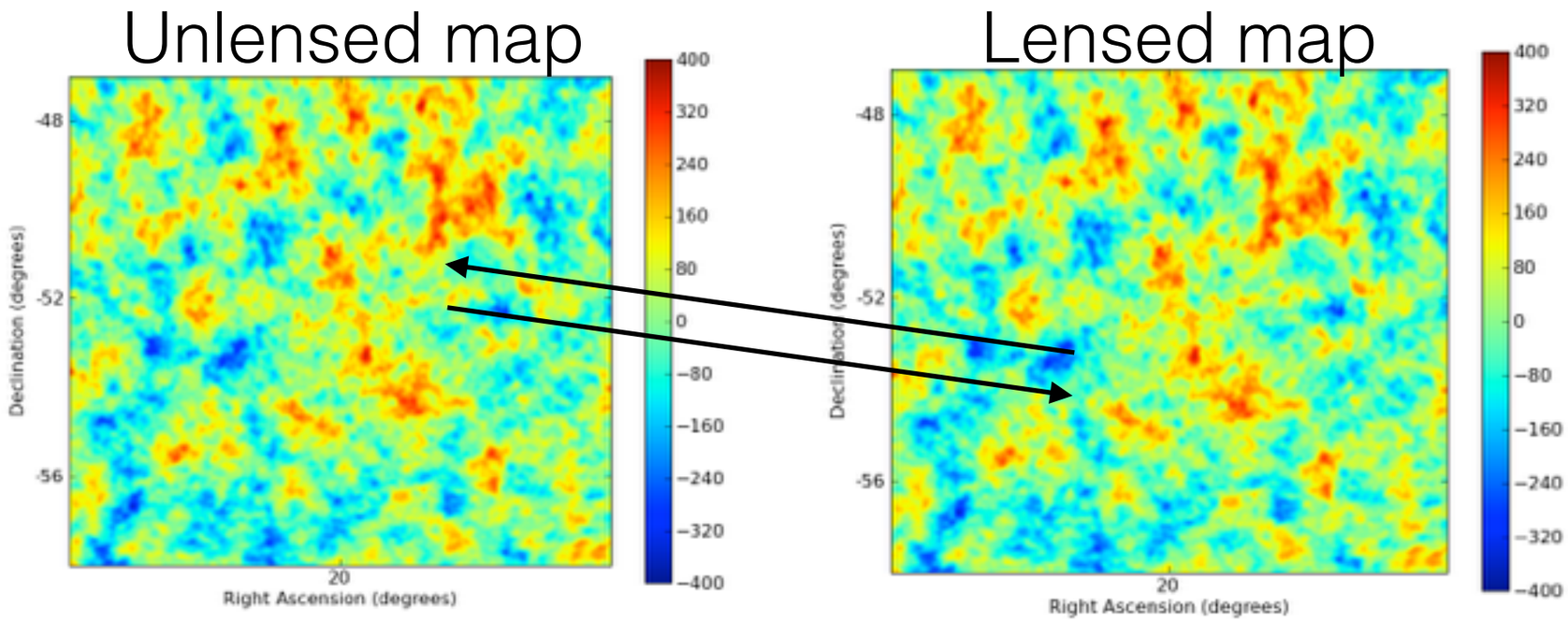

Shift pixels backward using LSS map to reconstruct unlensed CMB

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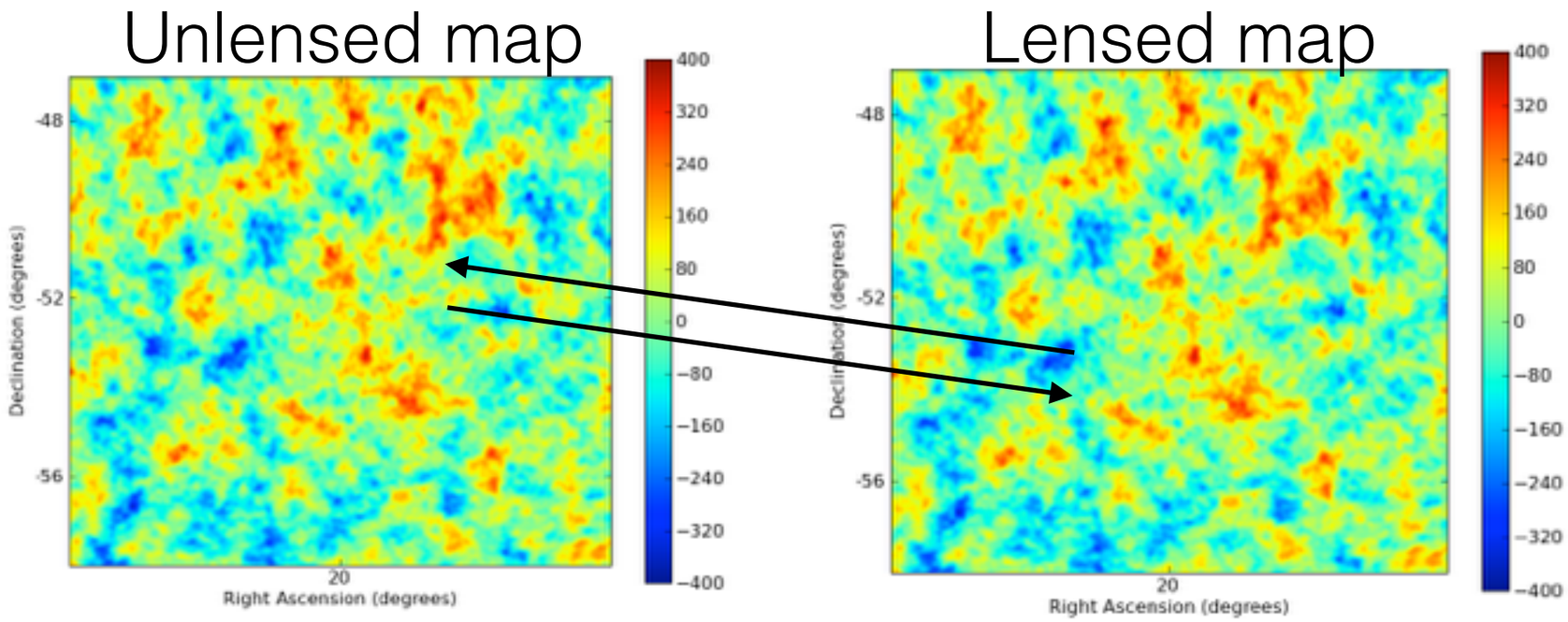

Shift pixels backward using LSS map to reconstruct unlensed CMB

- Need template of LSS from either internal CMB lens map reconstruction and/or LSS tracer like CIB
  (see e.g. Sherwin & Schmittfull, 2015, 1502.05356)

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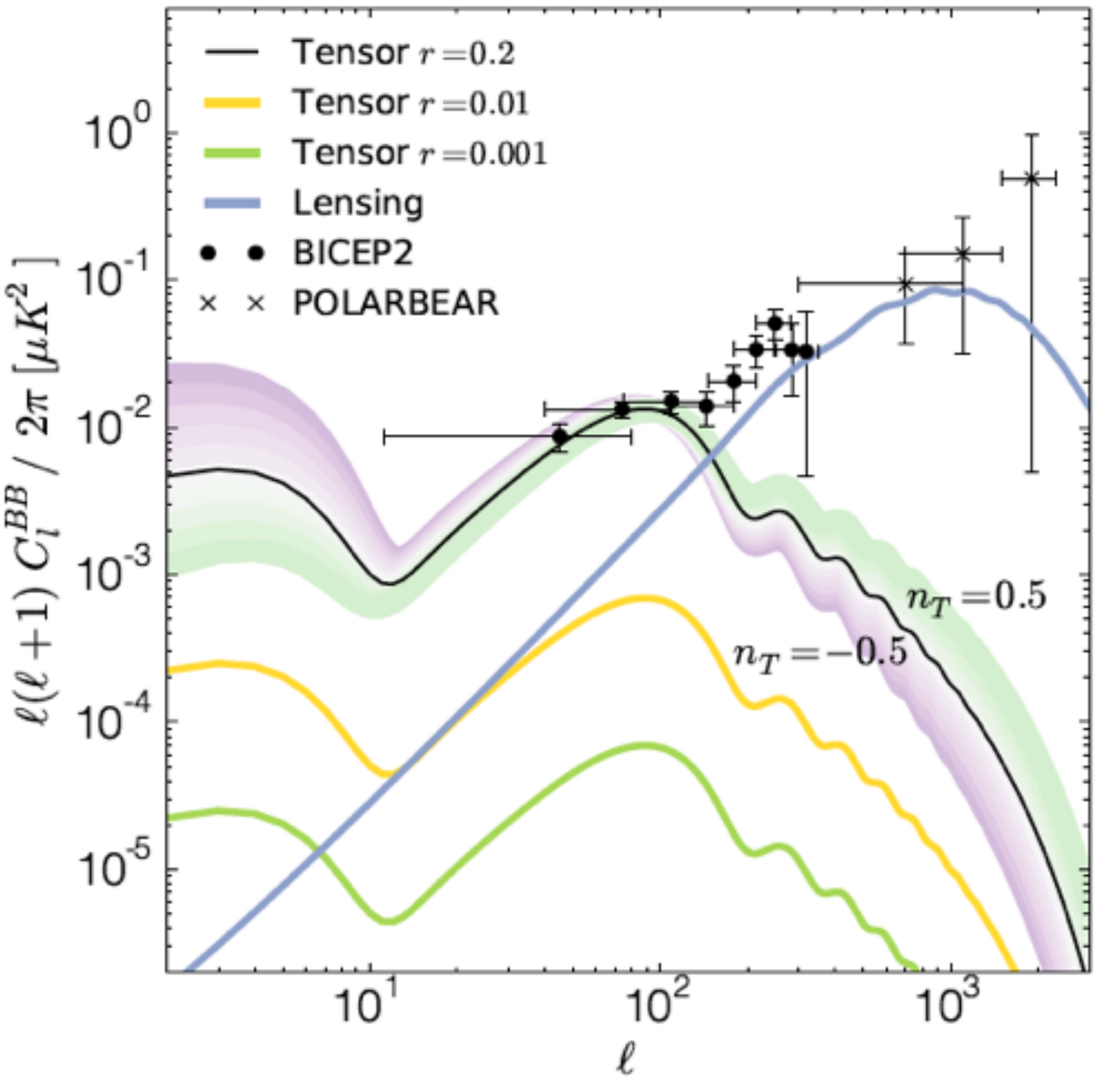
Want to measure the amplitude (r) and scale dependence (n_T) of primordial B-mode power



Simard, Hanson, Holder 2014, 1410.0691

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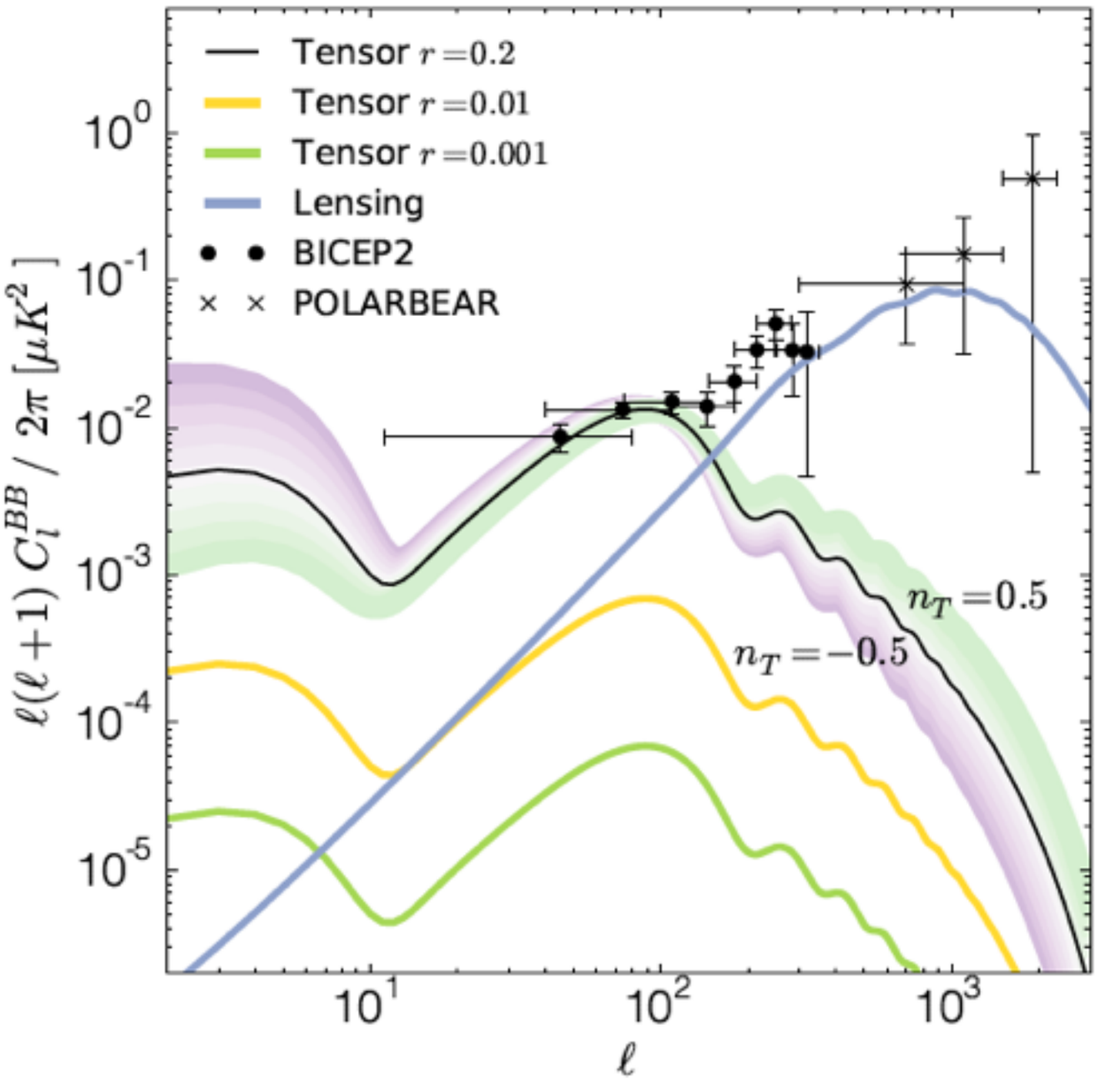
$n_T = -r/8$ is consistency relation of single-field, slow roll inflation



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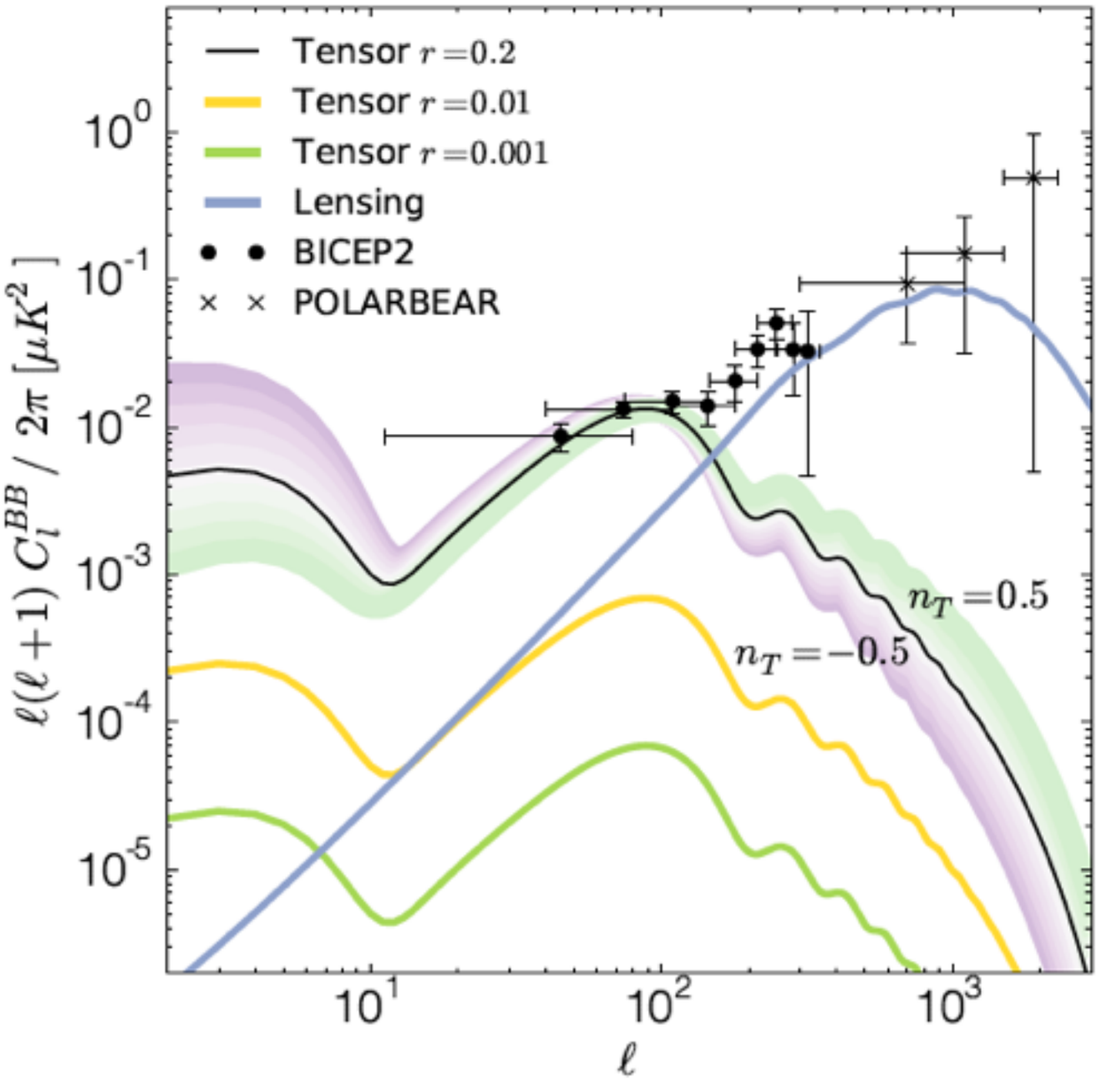
B-modes from gravitational lensing are a contaminant



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$$\sigma(r) \propto \sum_l \sqrt{\frac{2}{(2l+1)f_{\rm sky}}} (C_l^{\rm BB,lens} + N_l^{\rm BB})$$

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- With map of LSS and CMB E-mode map, can estimate CMB B-mode map from lensing

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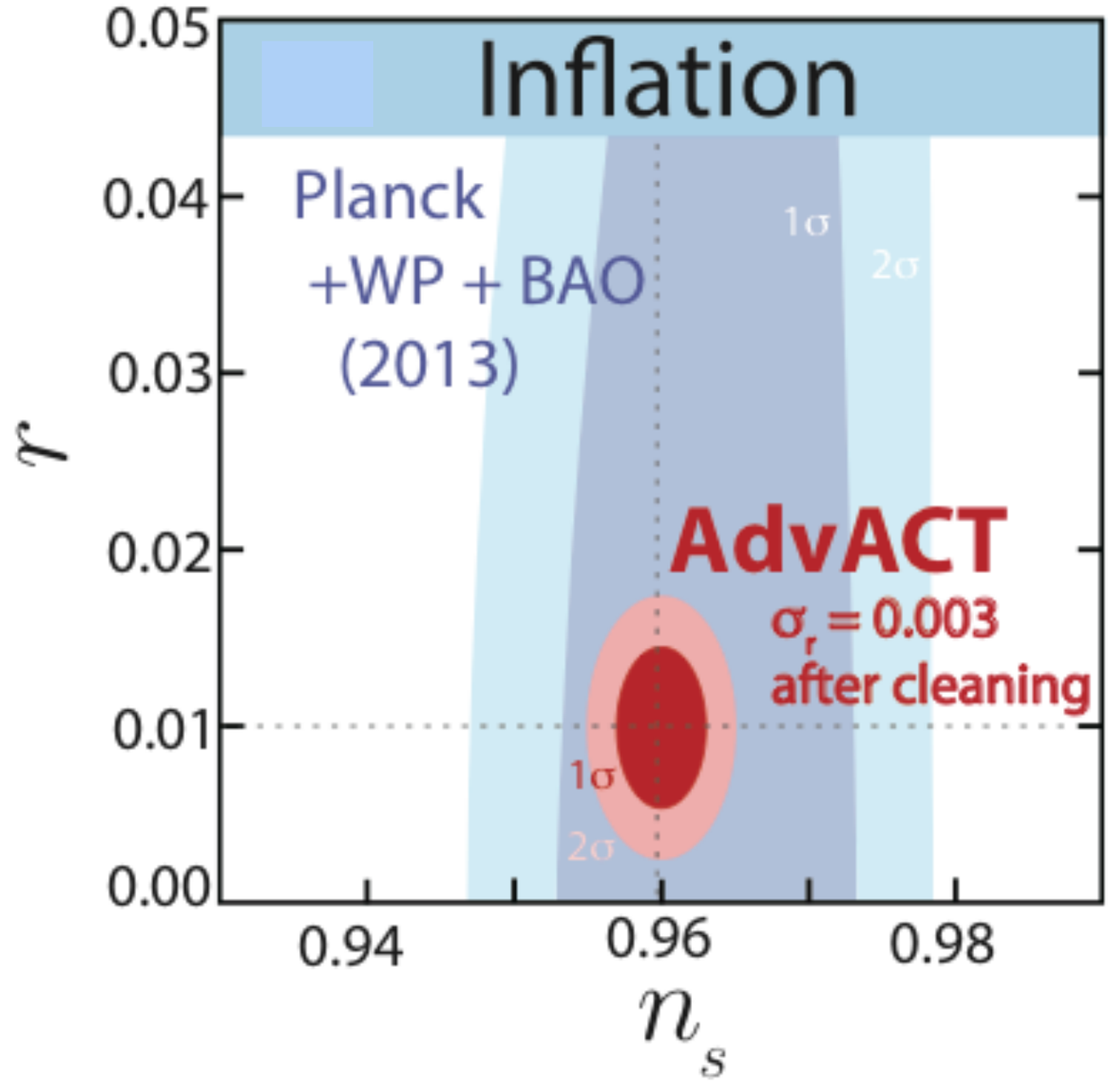
- With map of LSS and CMB E-mode map, can estimate CMB B-mode map from lensing

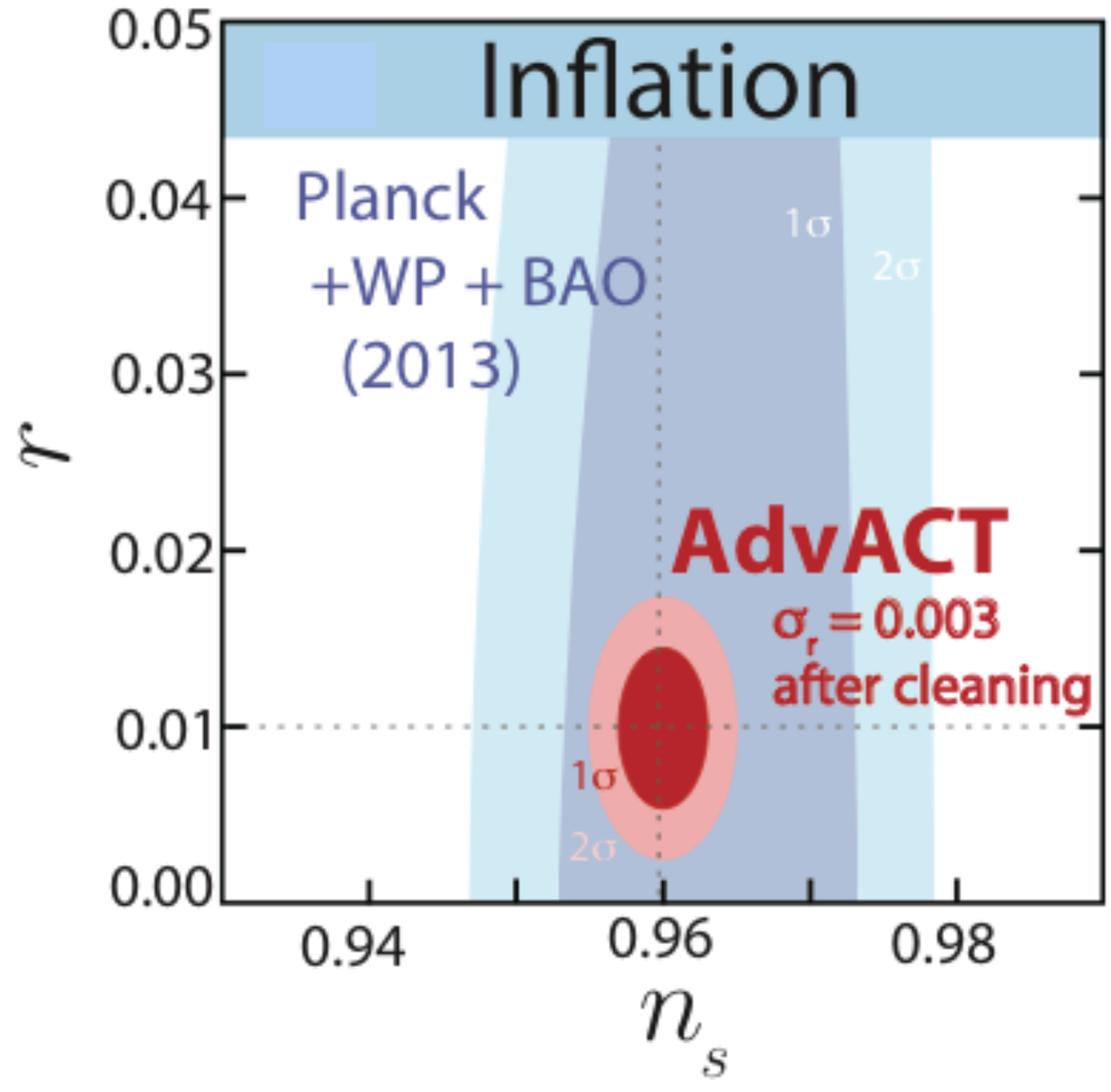
  - Need range of scales (100 < l < 1000), including small-scales as they contribute to large-scale B-mode power

AdvACT: Inflation Forecast



AdvACT: Inflation Forecast

AdvACT will survey
50% of sky



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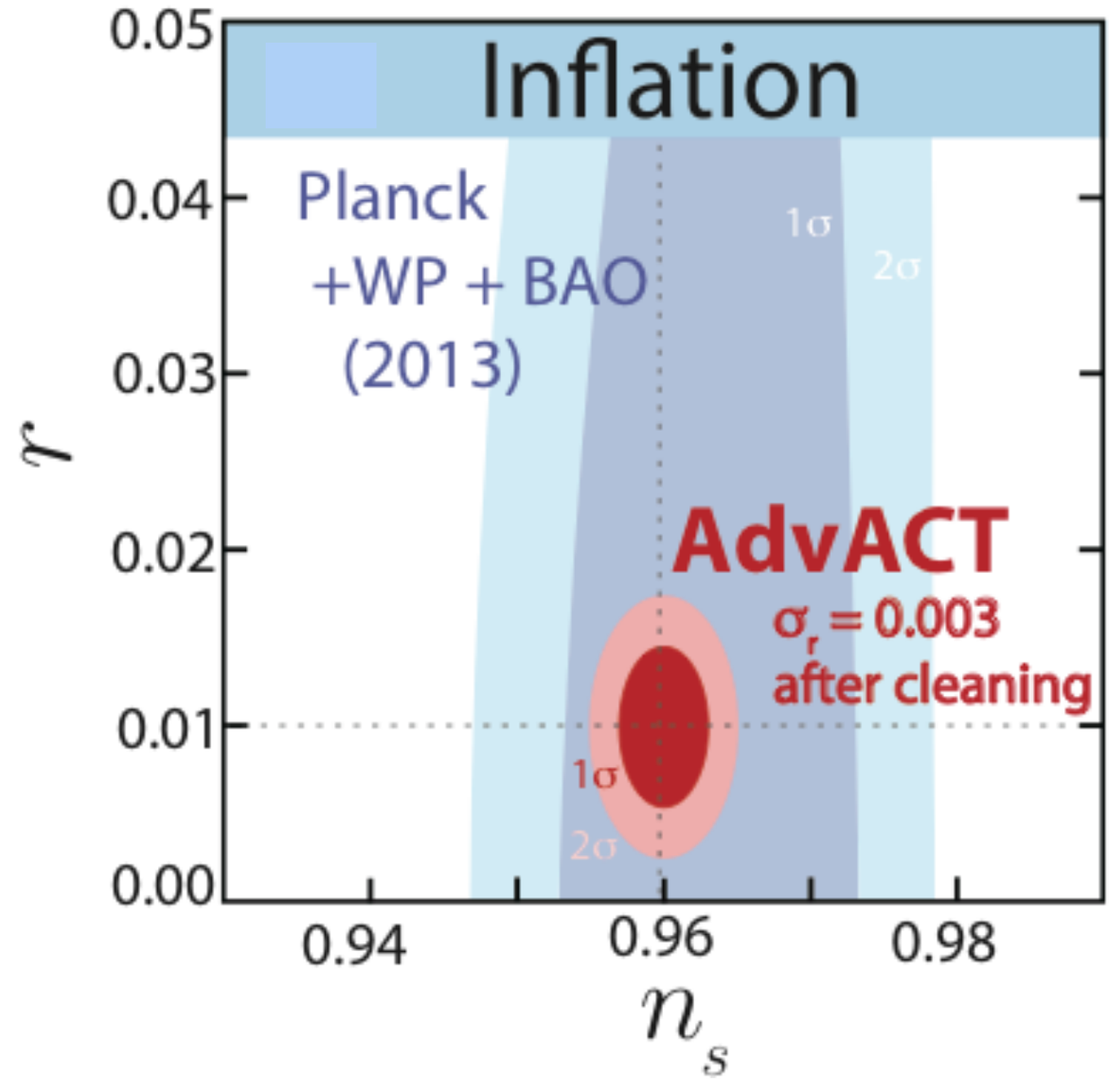
have 5 frequency
channels



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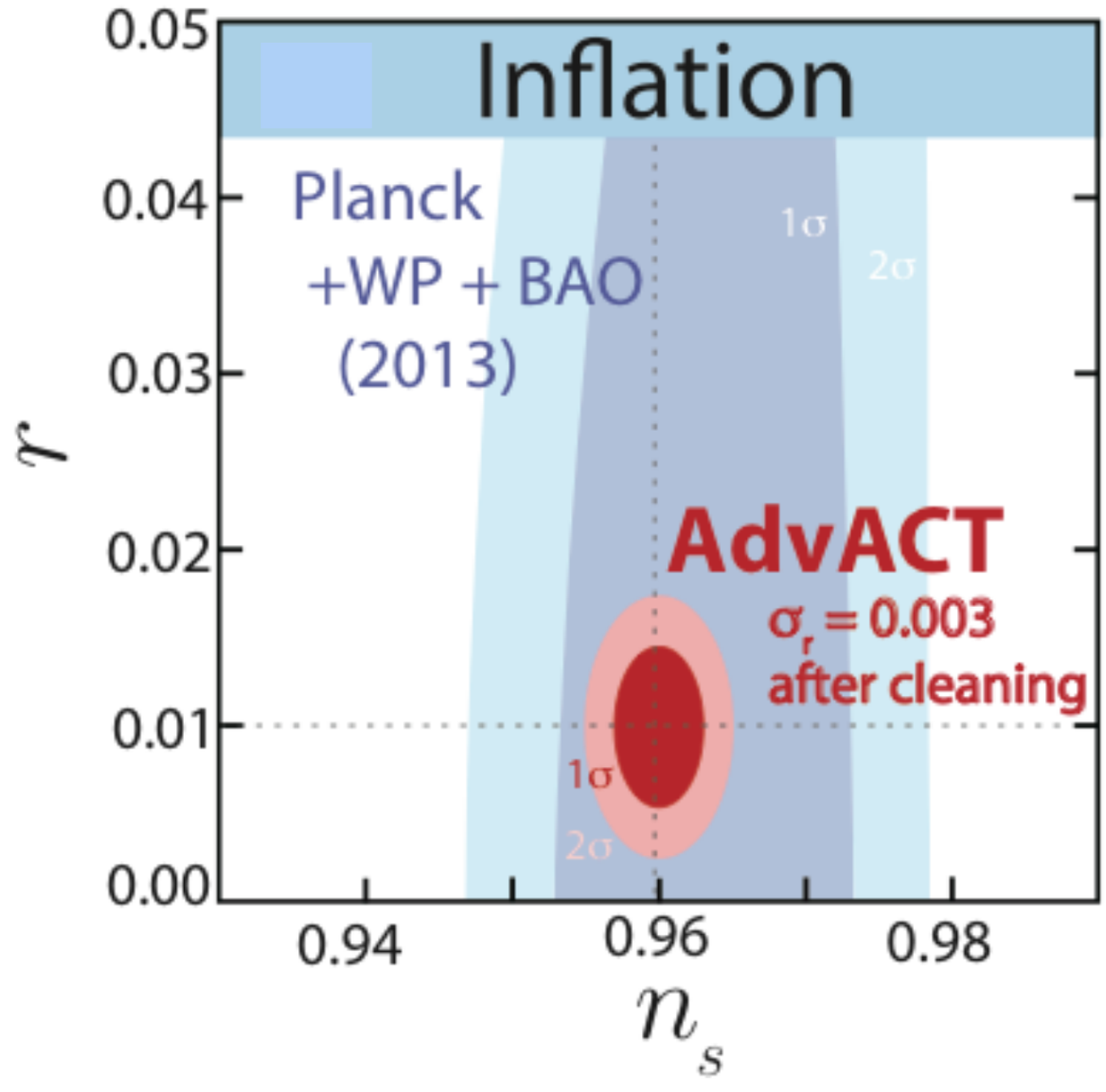
have a HWP to get to
ell ~ 50



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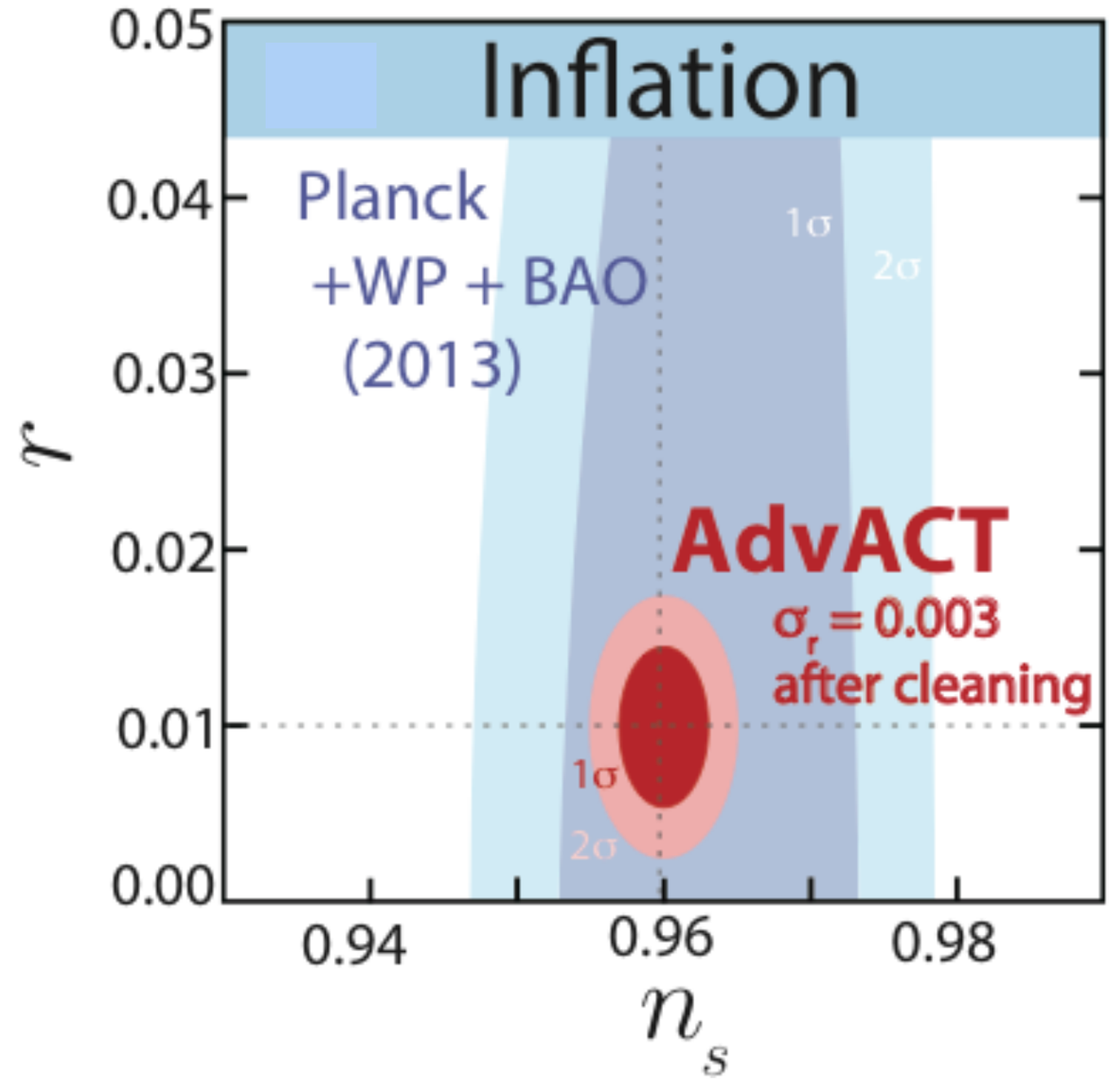
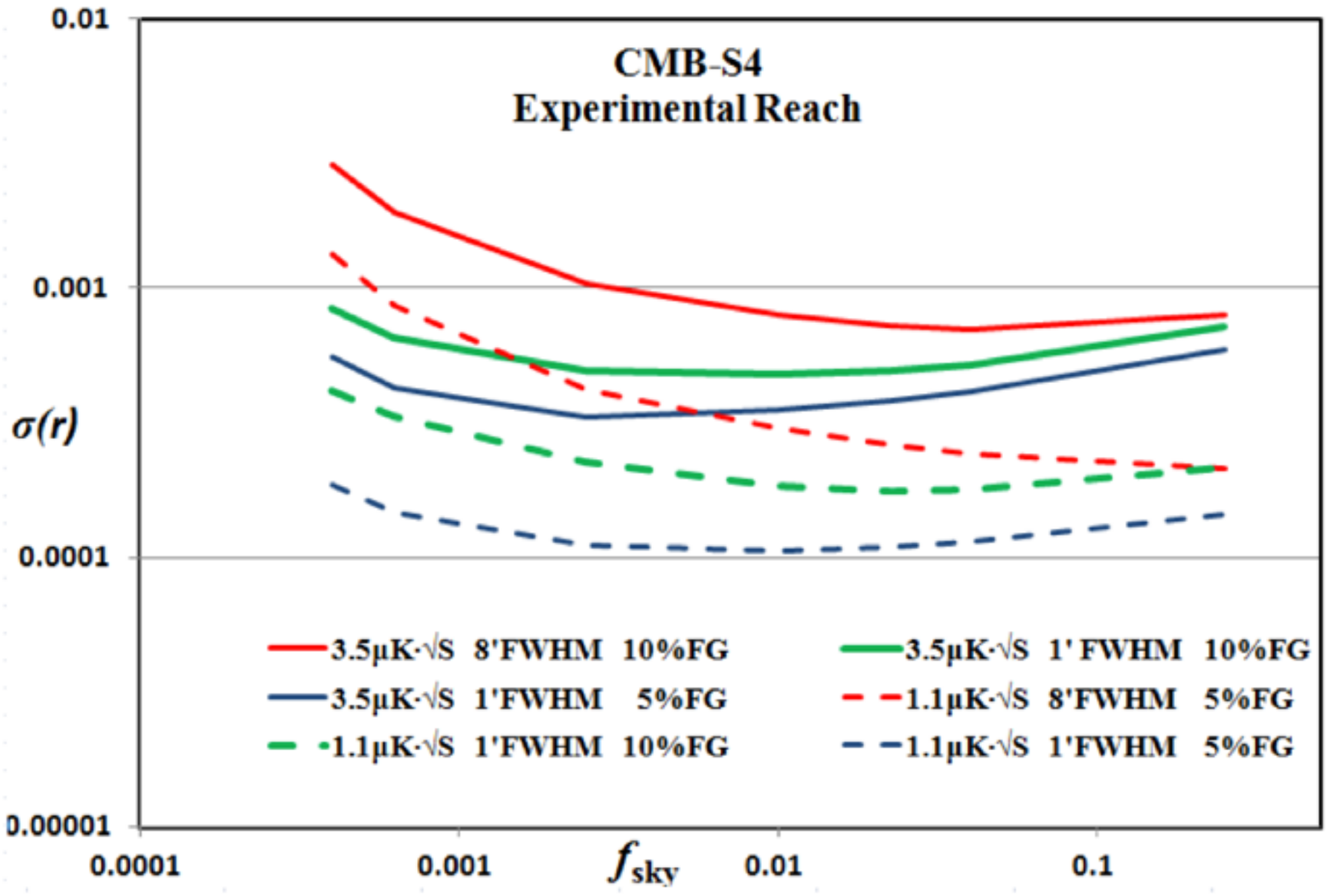
have small-scale CMB
to delens



CMB-S4: Inflation Forecast



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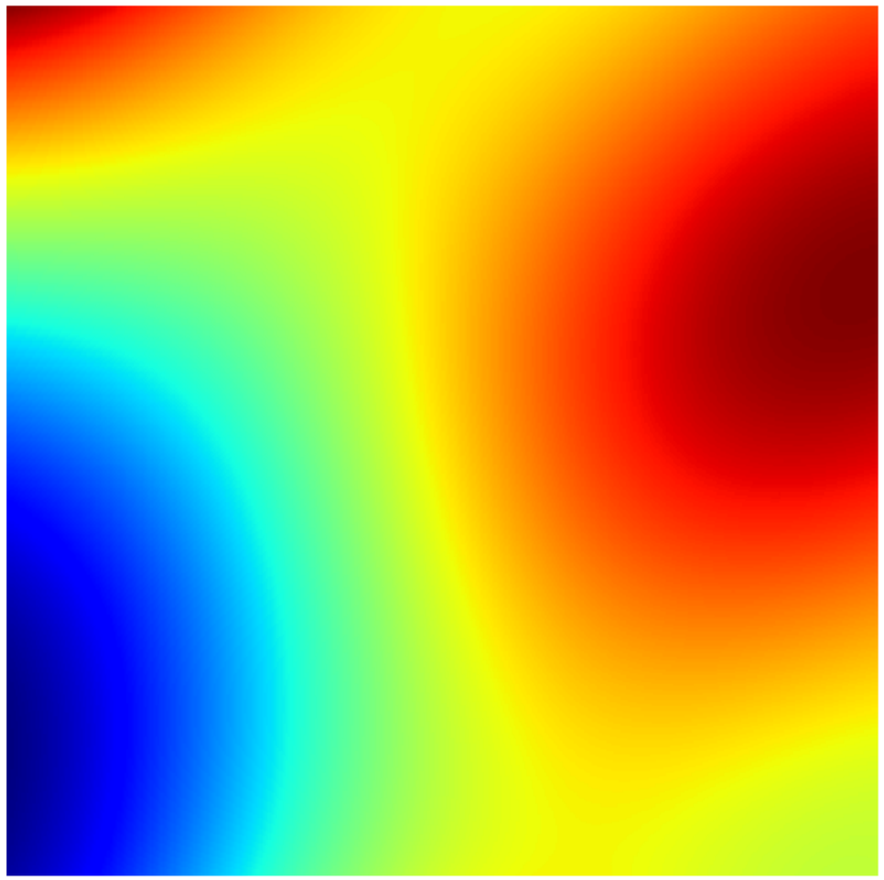
CMB Lensing on Small Scales

Unlensed CMB

Noiseless unlensed CMB sim

20’ x 20’ patch

Mostly gradient



CMB Lensing on Small Scales

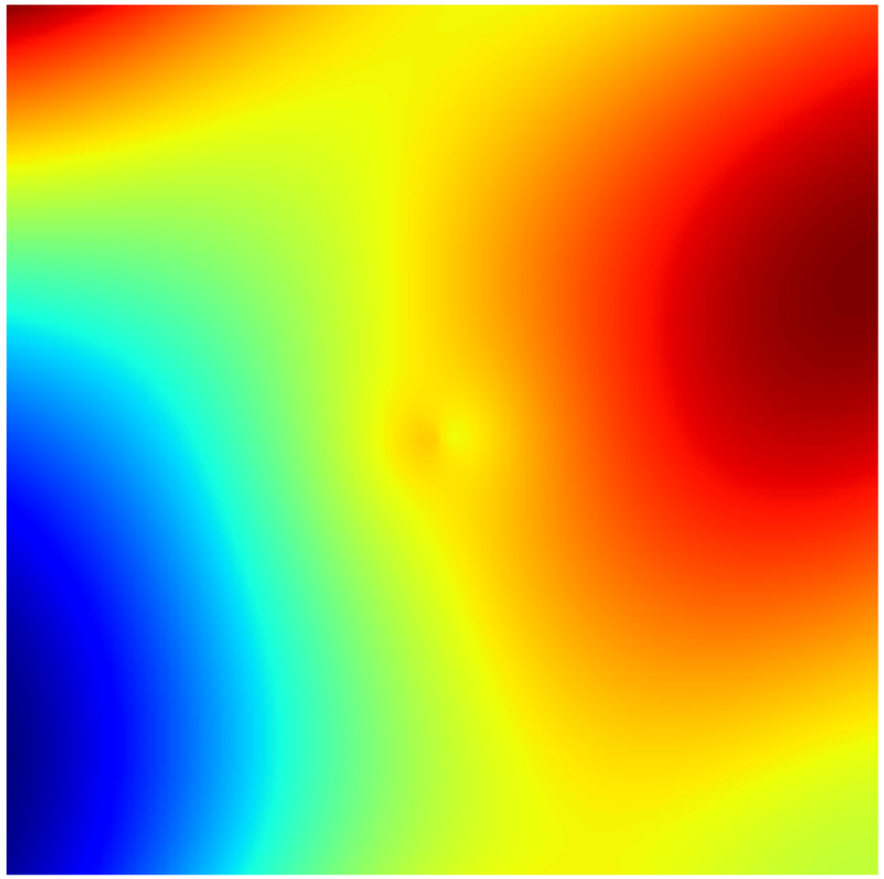
Noiseless lensed CMB sim

20’ x 20’ patch

Lensed by $M_{180} = 2 \times 10^{15}$ Msun

Lensing signal on Mpc / arcmin scales

Lensed CMB



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CMB Lensing on Small Scales

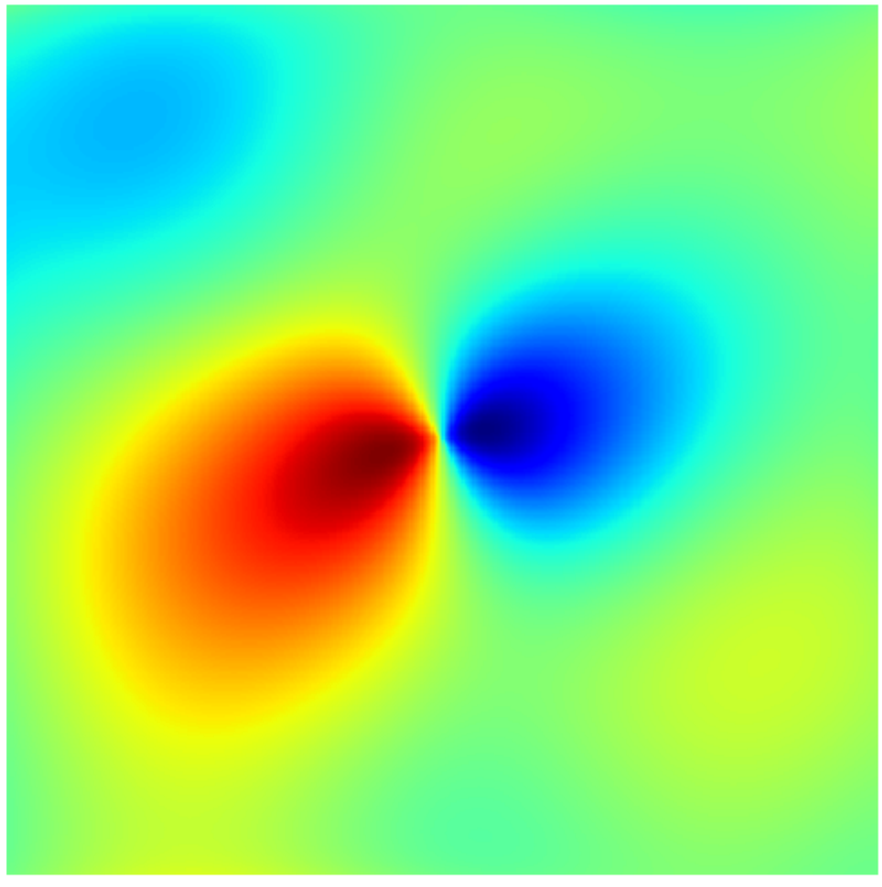
Difference of lensed and unlensed CMB

20’ x 20’ patch

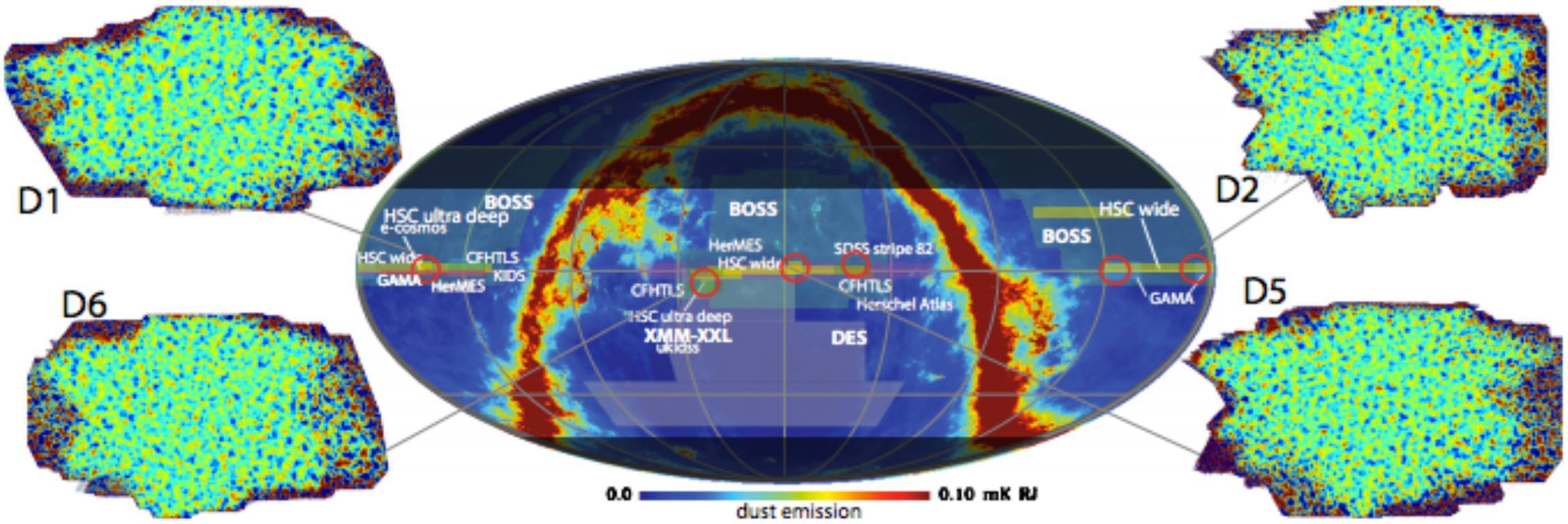
Characteristic dipole along the direction of gradient

Dipole signal is of the order of ~1-10uK

Difference Map



ACTPol First Season Maps



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Stacked ~12,000 CMASS Galaxies

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Galaxies from SDSS-III/BOSS DR10

CMASS ("constant mass") galaxies have similar selection as LRGs

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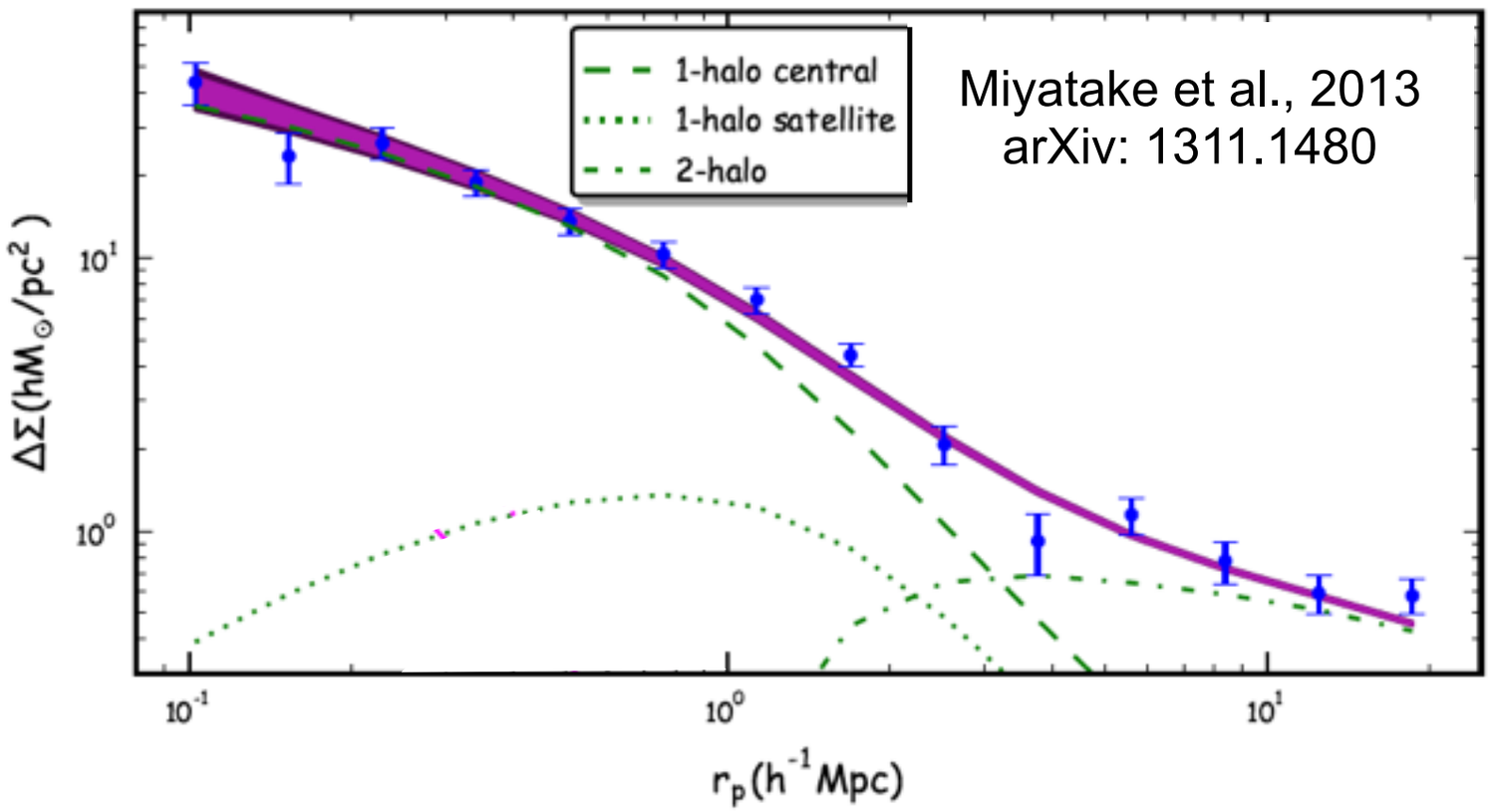
Stacked ~12,000 CMASS Galaxies

Galaxies from SDSS-III/BOSS DR10

CMASS ("constant mass") galaxies have similar selection as LRGs

Galaxies chosen because have optical weak lensing mass estimates

Weak lensing using CFHTLS

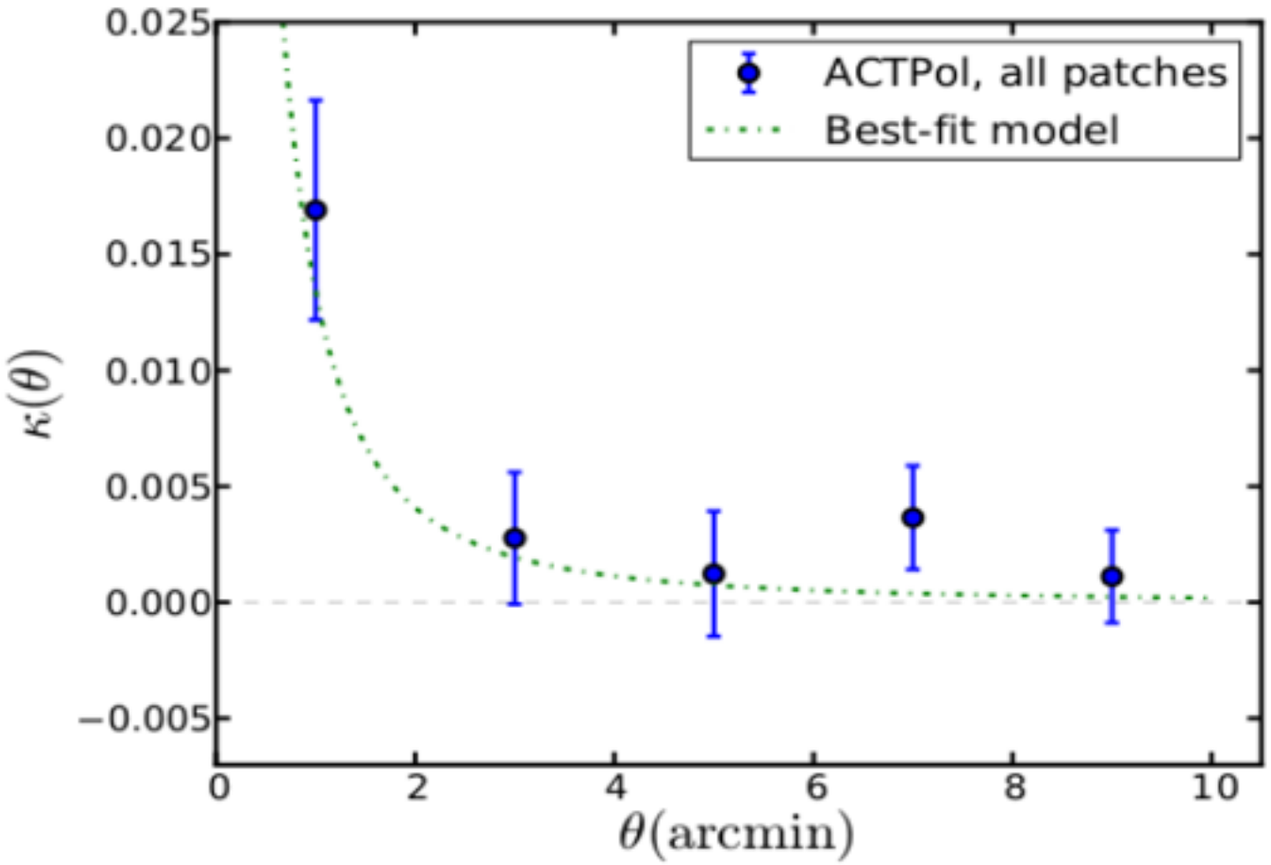


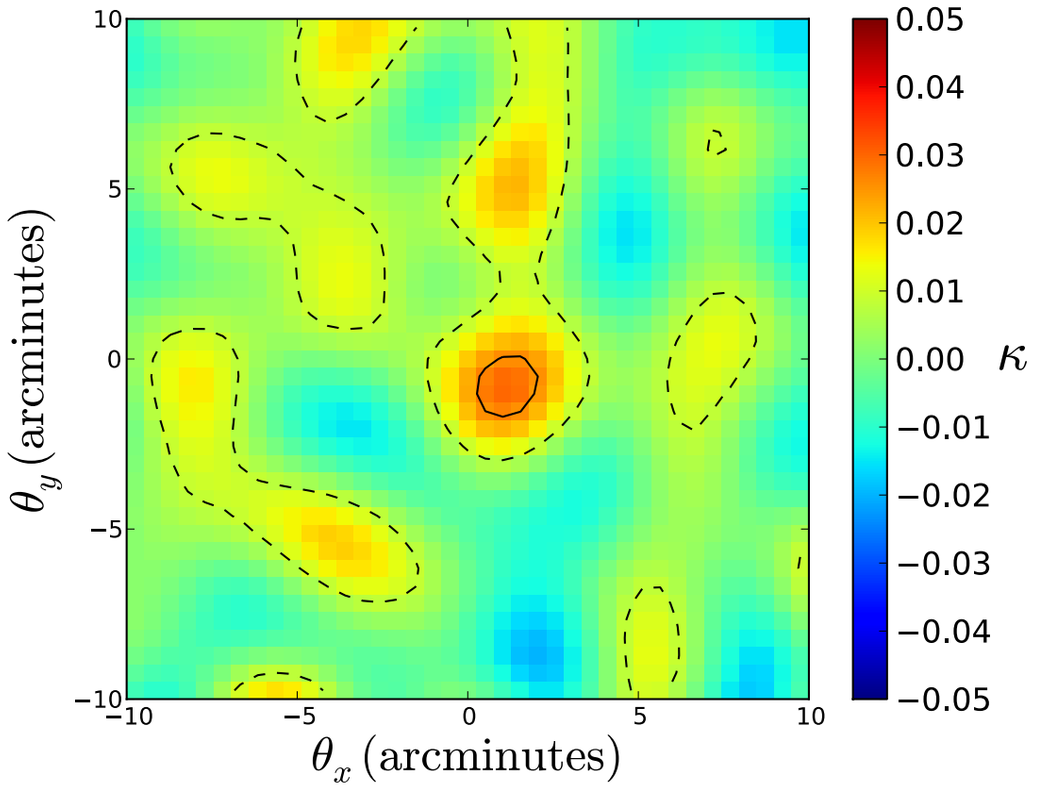
Miyatake et al., 2013
arXiv: 1311.1480

$$M_{200} = (2.3 \pm 0.1) \times 10^{13} h^{-1} M_\odot$$

ACTPol: First Detection of Lensing of the CMB by Dark Matter Halos

Madhavacheril, Sehgal, et. al., PRL, 114, 2015

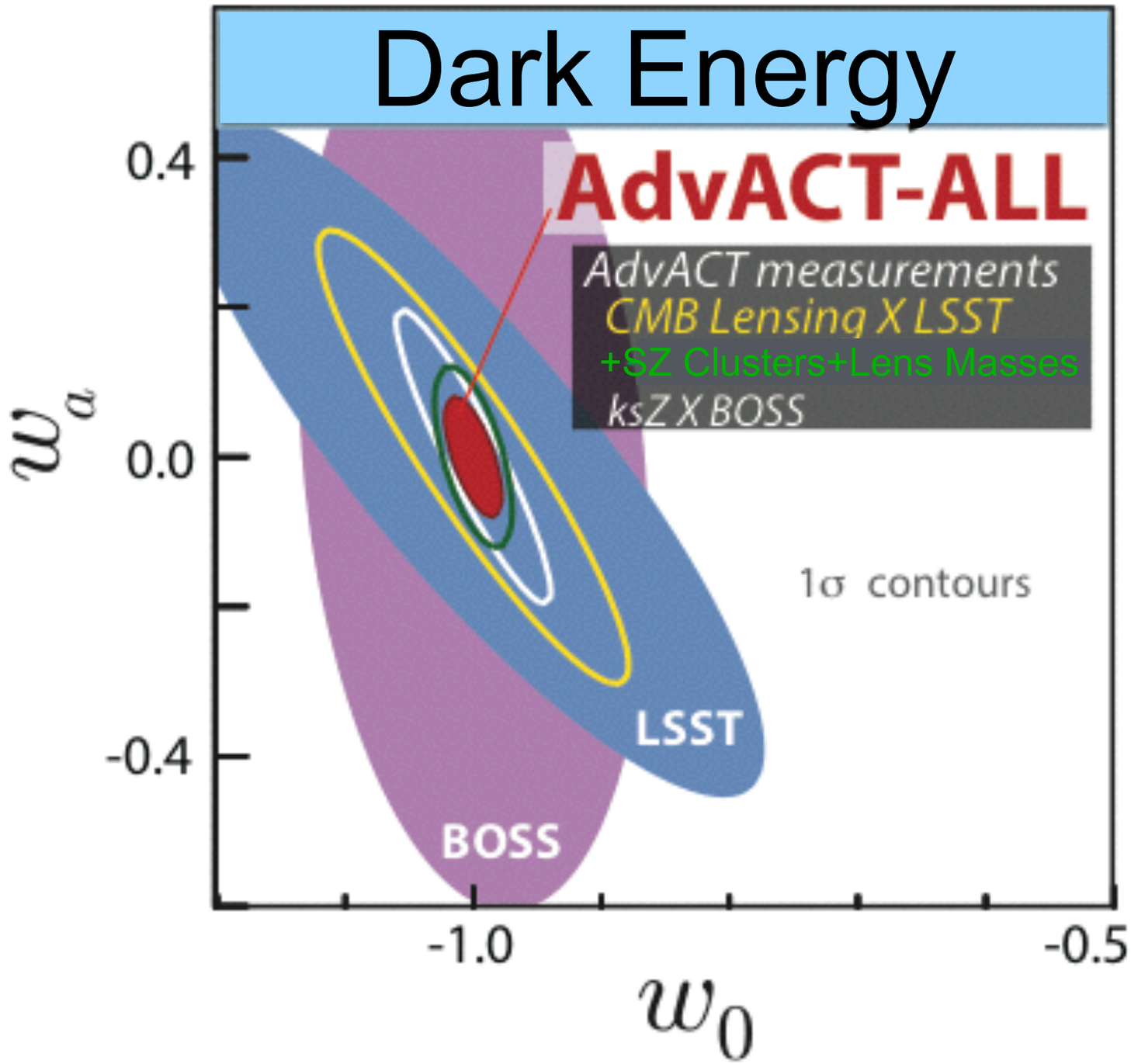




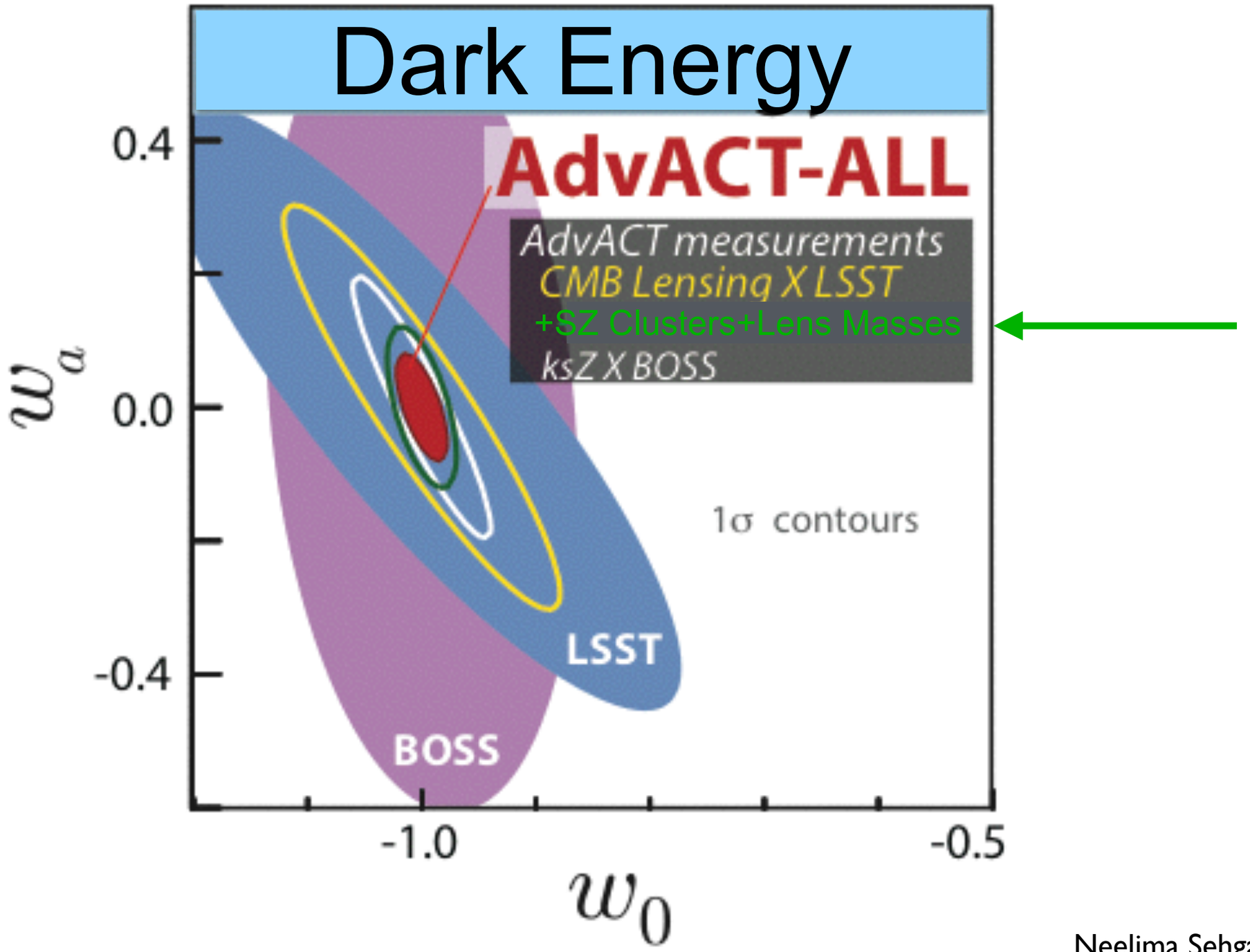
We detect halo lensing from 12,000 stacked CMASS galaxies at S/N of 3.2 sigma

Best fit: $M_{200} = (2.0 \pm 0.7) \times 10^{13} h^{-1} M_\odot$ and $c_{200} = 5.4 \pm 0.8$

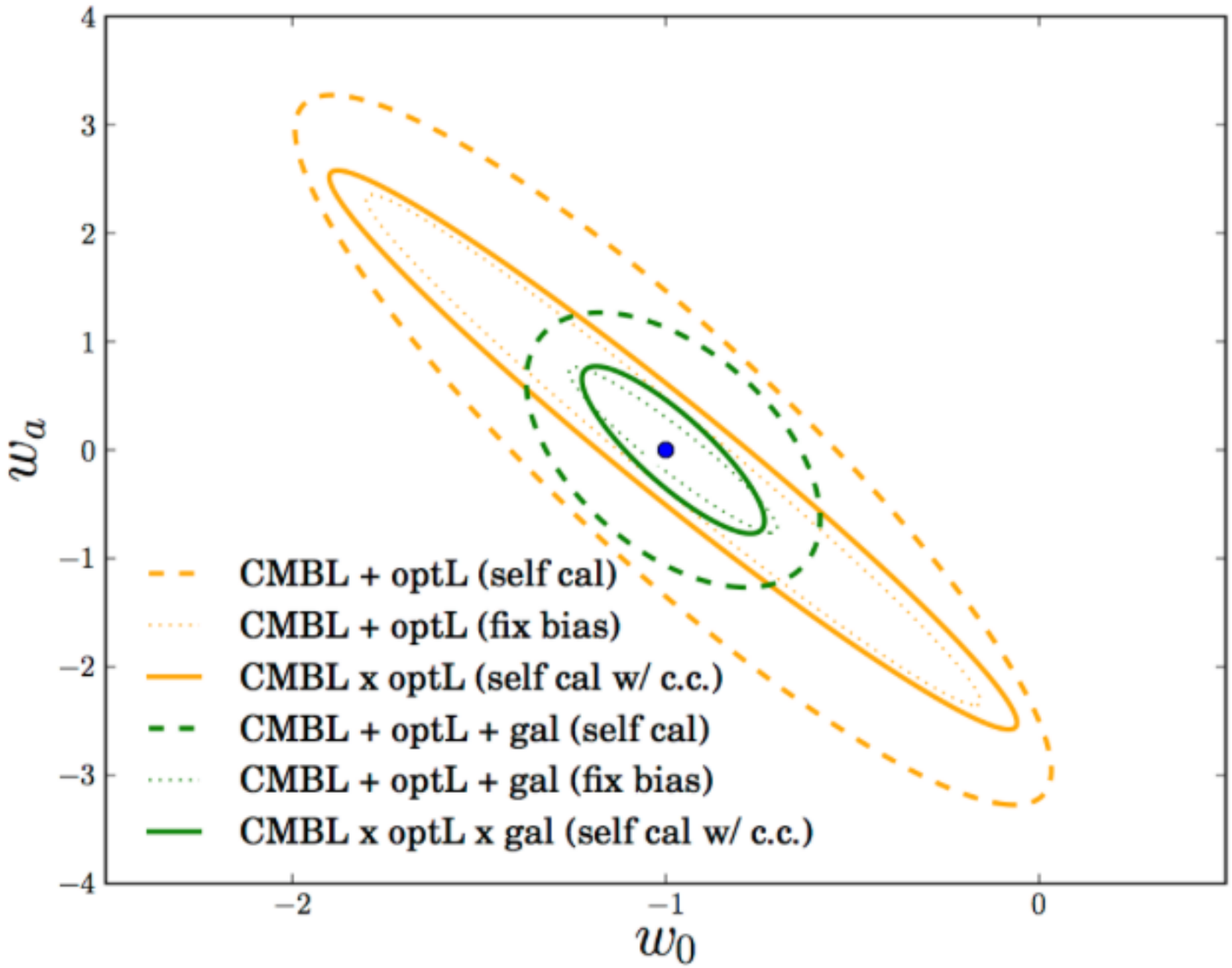
AdvACT: Dark Energy Forecast



AdvACT: Dark Energy Forecast

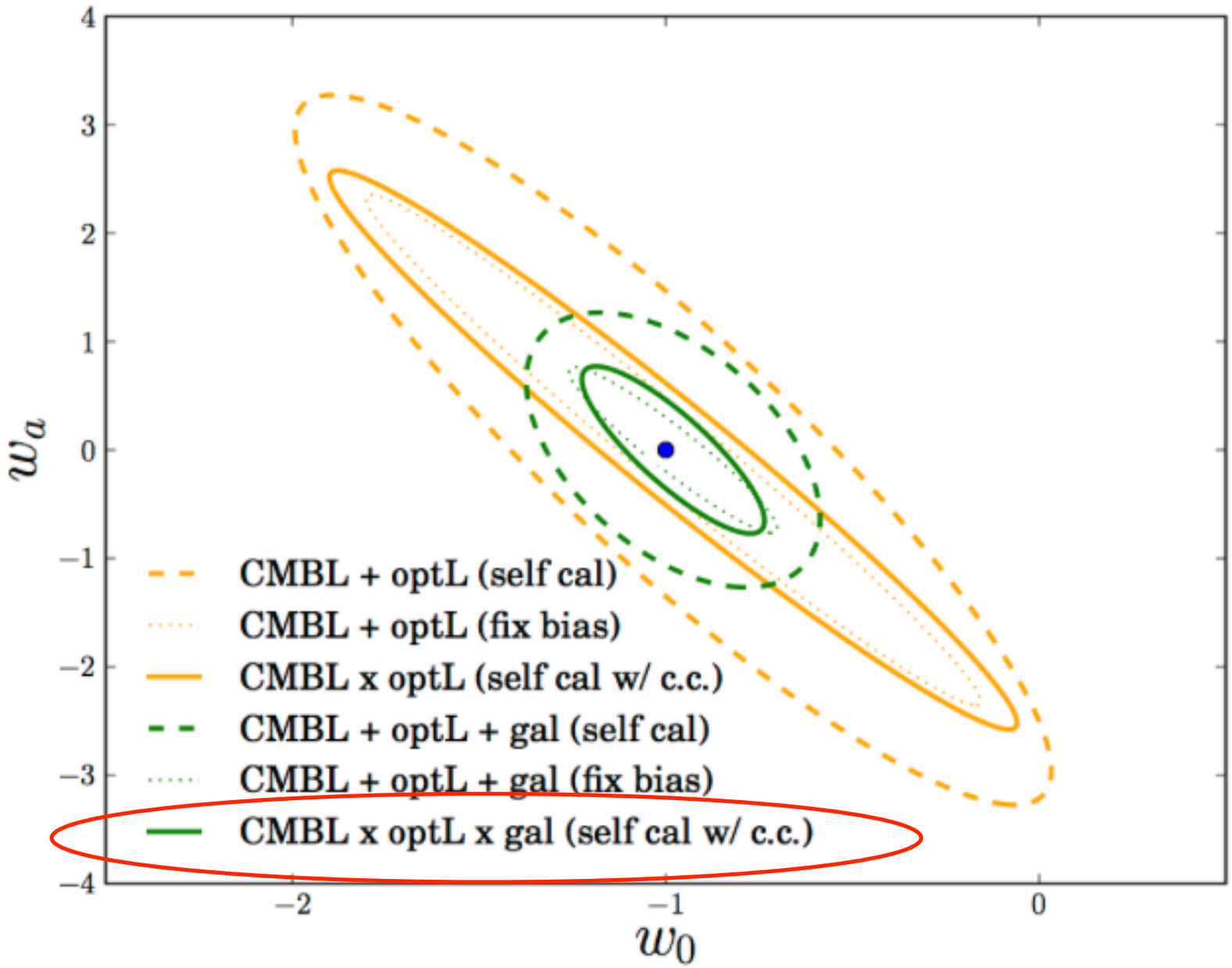


CMB Lens Cross-Correlations



Das et al, 2013, “Can CMB Lensing Help Cosmic Shear Surveys”

CMB Lens Cross-Correlations



Das et al, 2013, “Can CMB Lensing Help Cosmic Shear Surveys”

Outline

- Intro to ACTPol, AdvACT, CMB-S4
- Neutrino Mass from CMB Lensing
- Primordial Gravity Waves and Delensing
- CMB Halo Lensing/CMB Lensing Cross-Correlations as Probes of Dark Energy
- Conclusion

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Conclusion

- May detect neutrino mass with CMB lensing
- Probe r ~ 0.01 with AdvACT and r~0.001 with CMB-S4
- Explore Dark Energy with CMB in many ways including CMB halo lensing and CMB lens cross-correlations with redshift and shear surveys
- Future CMB surveys are important complement to large-scale structure surveys